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TECHNOLOGY REVIEW

BUSINESS • OPPORTUNITY • IMPACT

EXCLUSIVE REPORT

EXTREME SOFTWARE

WHAT IF SOFTWARE FIXED ITS OWN BUGS, ADAPTED TO YOUR NEEDS, AND NEVER CRASHED? TWO PC PIONEERS REVEAL THEIR PLANS TO MAKE IT HAPPEN.

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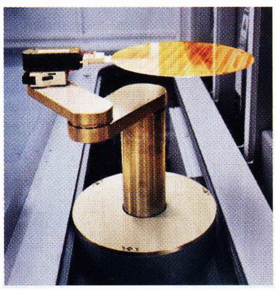
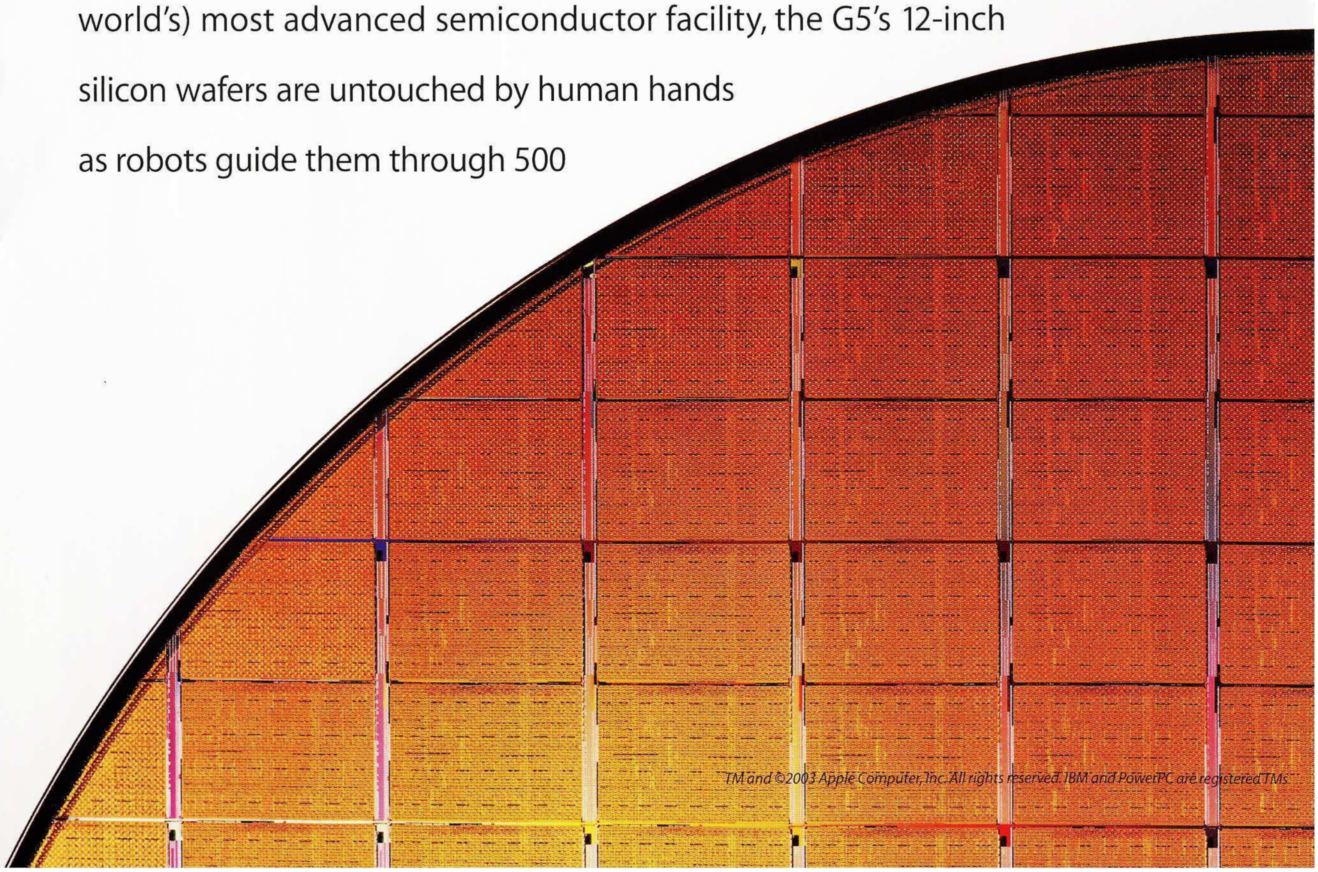
The dawn of a new PC era.

For the last decade, every processor chip in every personal computer in the world has been based on 32-bit architecture. It was the best technology we had. Until today. Introducing the revolutionary PowerPC G5 processor, the world's first 64-bit processor for personal computers.



The world's most advanced personal computer chips are manufactured in the world's most advanced semiconductor factory.

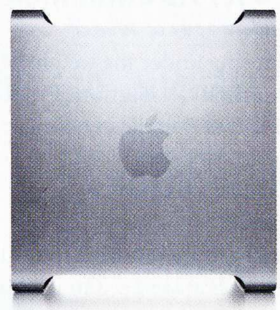
Before now, a chip this formidable could only be found in the world's fastest servers and supercomputers. Which is precisely where the G5 chip came from. Developed by IBM and Apple,® the G5's DNA is from the core of IBM's highest-performance, 64-bit POWER4 processor. But just as impressive as the G5's pedigree is how it's manufactured. In IBM's (and the world's) most advanced semiconductor facility, the G5's 12-inch silicon wafers are untouched by human hands as robots guide them through 500



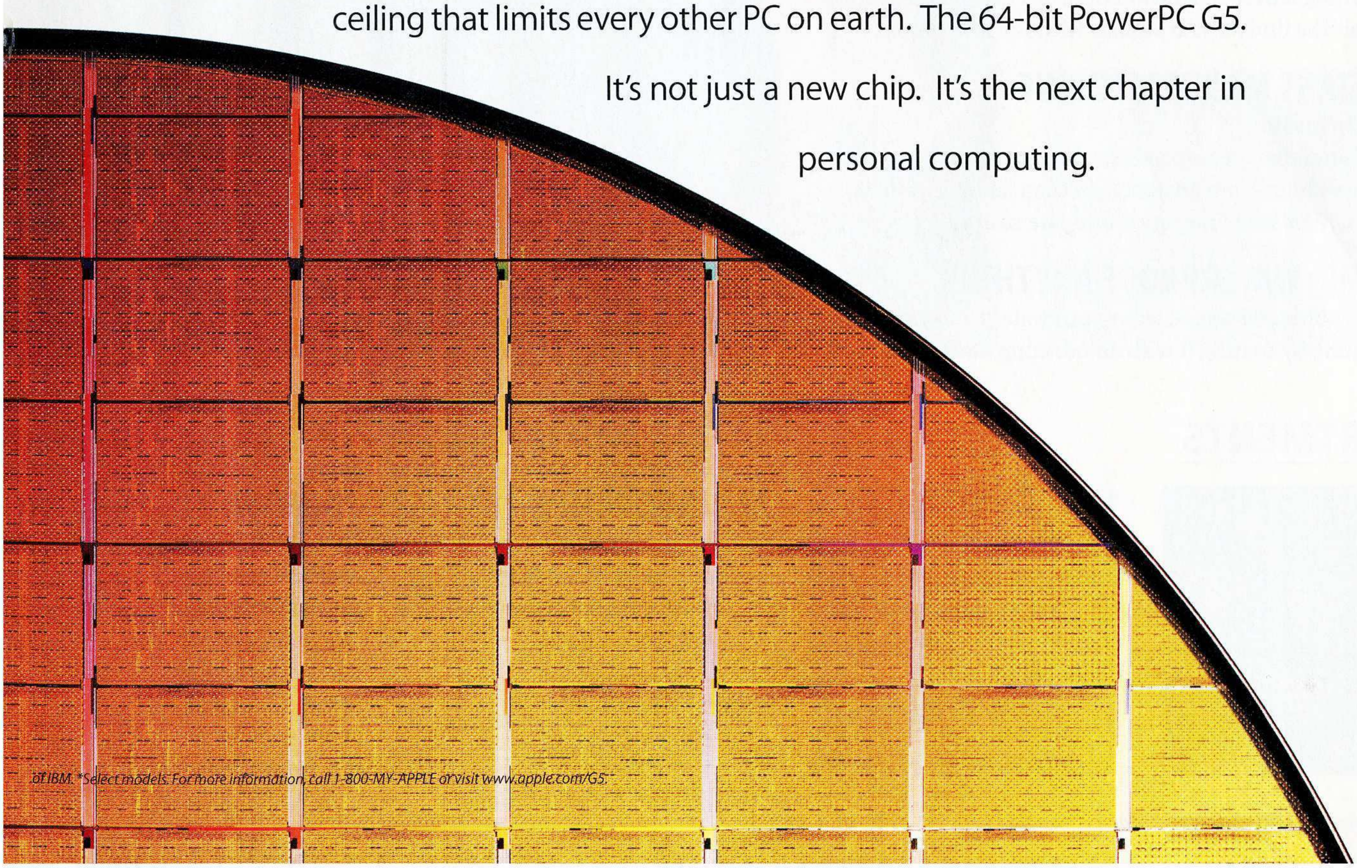
The 64-bit processor.

processing steps, creating 58 million transistors and connecting them with over 1000' of copper wire that's less than 1/800th the width of a human hair.

The new PowerPC G5 has a 1-gigahertz frontside bus* that moves data in and out of the processor almost twice as fast as the competition, removing a key bottleneck that limits performance. And it can support more than 200 in-flight instructions at a time – 71% more than the 32-bit Pentium 4. Perhaps most importantly, the G5's 64-bit architecture can address dramatically more memory – over 4 billion times more than 32-bit chips – so that systems built around the G5 can shatter the 4-gigabyte memory ceiling that limits every other PC on earth. The 64-bit PowerPC G5. It's not just a new chip. It's the next chapter in personal computing.



The world's first 64-bit desktop processor can only be found here: Inside the new Power Mac® G5, the world's most powerful personal computer.



of IBM. *Select models. For more information, call 1-800-MY-APPLE or visit www.apple.com/G5.

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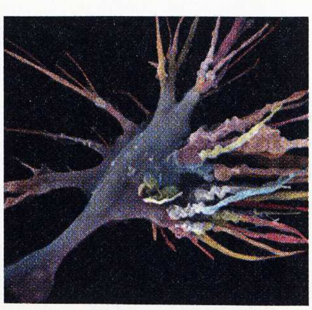
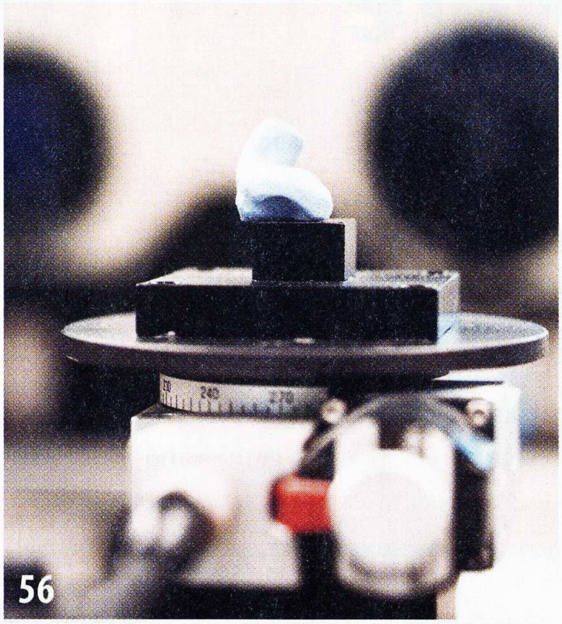


Technology Review
Volume 106, Number 9
November 2003

"It may be hubristic, but we're trying to pioneer a new type of interface." —*Mitch Kapor, p. 44*



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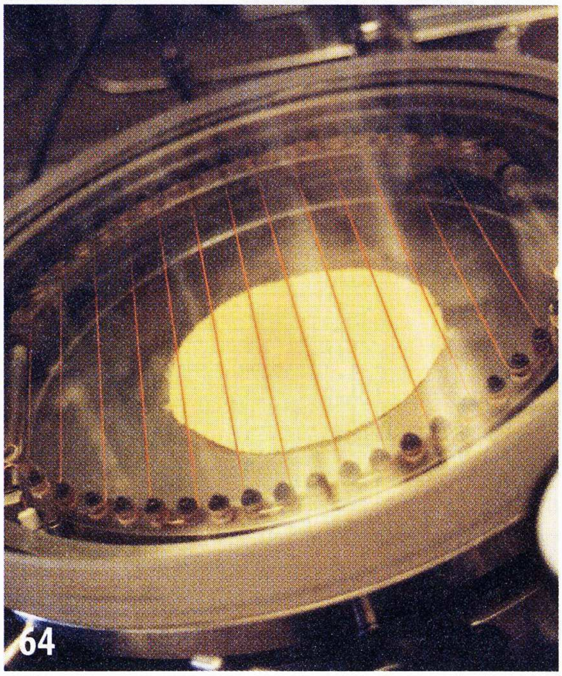

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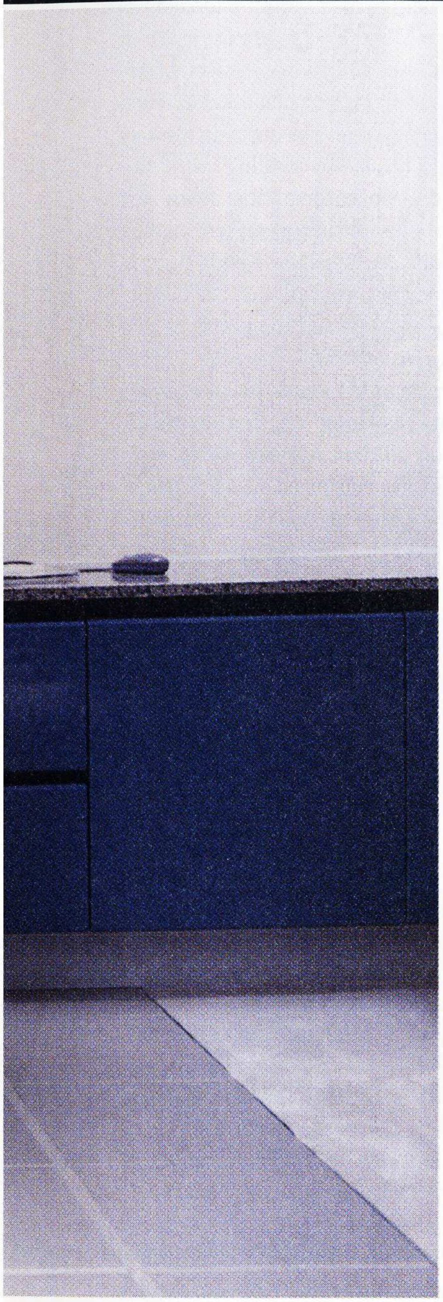

IN EVERY ISSUE

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FEATURED ONLINE

- Research news, updated daily
- TechnologyReview.com blog, providing commentary on computing and its impact
- Innovation futures: try to predict technology's course
- And more...

Can Software Be Saved?

IT'S THE SOFTWARE THAT COUNTS. WE MAY GET excited about the latest hardware—computers with sleek designs, ever bigger hard drives, faster processors, and flashy features like wireless connections. But in the end, it's the software that keeps us buying, because without software—whether for word processing and presentations, playing games and music, or keeping the family photos—we can't use any of that hardware power. For all the good it does us, however, software has a world of problems: it's hard to use, and it crashes far too often. That's largely because it's written by human programmers, and with millions of lines of code in a typical application, bugs are inevitable. In fact, in 2000 approximately one-fourth of all U.S. commercial software projects were canned—costing firms a staggering $67 billion.

Which is why *Technology Review* has paid so much attention over the past few years to innovative efforts aimed at fixing what ails software. Our July/August 2002 cover story, "Why Software Is So Bad," set the standard, and software quality assurance made our "10 Emerging Technologies That Will Change the World" list in February 2003. Now, with this month's cover story and special report "Extreme Software," we are turning our attention again to this important topic with exclusive articles on a pair of efforts that could transform the software industry.

Our package is built around two of the most interesting, colorful, and effective leaders in the field: Charles Simonyi and Mitch Kapor. As a Xerox Palo Alto Research Center researcher in the 1970s, Simonyi produced the first "what you see is what you get" word-processing program. He went on to become chief architect at Microsoft. Kapor, as founder of Lotus Development, did more than almost anyone to usher in the PC revolution of the 1980s by bringing the world the Lotus 1-2-3 spreadsheet that turned desktop computers into truly useful business tools.

Now, these two pioneers are tapping their fortunes to bankroll efforts aimed at establishing a new software era.

Now these two pioneers are tapping their personal fortunes to bankroll separate efforts at establishing a new software era. Simonyi, with his startup Intentional Software, wants to automate much of code writing, thereby making programs dramatically less buggy. At the same time, he wants to make it easy for nonexperts to refine the programs they use—based not on their knowledge of programming but on what they *intend* for the software to do. You'll find the fascinating account of Simonyi's work in "Everyone's a Programmer" *(p. 34)*, by contributing writer Claire Tristram. Sidebars to this piece examine two other trends in the industry: "extreme programming," an innovative attempt to enhance the aspects of the code-writing process that work and throw out those that don't, and the development of "self-healing" software that fixes its own bugs before they become a problem for you.

Complementing this package is "Trash Your Desktop" *(p. 42)*, the story of Kapor and his ambitious project code-named Chandler. Chandler has the not-so-modest goal of revolutionizing the way we manage ideas—by ridding us of the need to dig up information from the assortment of applications represented by icons on our desktops. As Kapor puts it, software today is "too difficult, too limiting, and pretty severely so, and it's a raw deal." The idea behind Chandler is that computers should adapt to what their owners are working on, automatically bringing up all data relevant to the subject at hand. For our piece, writer Michael Fitzgerald secured the first in-depth journalistic access to the project—and we think you'll savor the changes it portends.

The story of this software revolution is just one element of a great issue. Debuting this month is a bimonthly column on the future of computing by Rodney Brooks, director of MIT's Computer Science and Artificial Intelligence Laboratory. Brooks, a world leader in AI and robotics, starts his new column with a bang by looking at a bold idea that may not be as far out as it seems: a direct brain-to-Internet interface.

Also new with this issue is "Launch Pad," a monthly department that offers an early look at the most exciting companies spinning off from universities around the world. Lifting off this month: Alnylam Pharmaceuticals, a company cofounded by Nobel laureate Phillip Sharp, who was also a cofounder of Biogen. Alnylam is based on the five-year-old discovery of RNA interference (RNAi) in animals, a natural process in which RNA molecules turn off the workings of particular genes. If it can be controlled in the lab, RNAi could turn into one of the most potent techniques for creating new drugs to come along in years.

Putting out a great magazine, like software design, entails a commitment to constant improvement. These new elements, combined with our evolving coverage of emerging technologies, create the framework for an even better window on the future of economic growth…and opportunity. **Robert Buderi**

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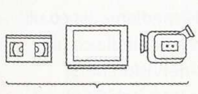

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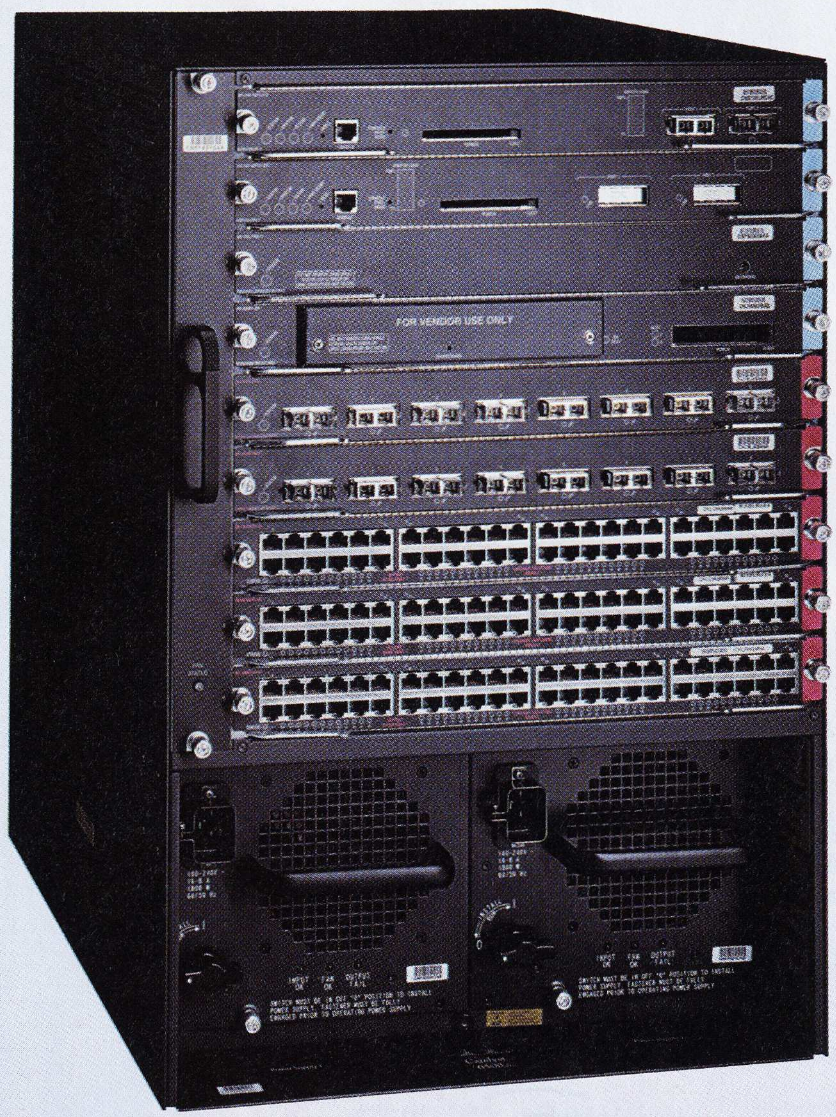

"Boeing may have been bluffing with the Sonic Cruiser....The company might be better at poker than you give it credit for."

BOEING'S BIG GAMBLE

THE ARTICLE "BOEING'S FLIGHT FOR Survival" (*TR* September 2003) highlights the contrasting marketing strategies employed by Boeing and Airbus for addressing the centralized-hub-airport issue. Centralized-hub routing originated in the early days of commercial aviation, when long-distance flights were punctuated by refueling stops. The advent of long-range transport planes eliminated the need for intermediate refueling, but airlines continued to favor routing via airports where they already had large maintenance facilities. This led the major airlines to develop such facilities into centralized hubs. The disadvantage of such hubs is that they compel airline customers to accept indirect routing. The Boeing 7E7 appears to offer a viable means of bypassing the centralized-hub system, and deserves the support of airport operators and passengers.

Marvin A. Moss
North Hills, CA

AN EVEN BOLDER GAMBIT WOULD BE serious pursuit of the blended-wing-body concept, a hybrid of a "flying wing" and a conventional airframe design that promises significant fuel efficiency gains. A blended-wing-body aircraft with the same wingspan as today's jetliners could carry more people and cargo. The crossover military applications—bomber, gunship, tanker, transport, and airborne laser all on the same airframe platform—make for some compelling economics. The government could even underwrite the $10 billion development, which would be recouped through discounts on military orders. Blended-wing-body has been proven with the B-2 bomber, and modern avionics controls could push the concept farther. Costs would be much lower because there would be no need to make this new plane stealthy.

David C. Herr
Berkeley, CA

AS A PILOT FOR A MAJOR AIRLINE, I must take issue with your editorial "Boeing's Slow-Death Hand" (*TR* September 2003). I would consider the Boeing 707, 727, 737, 747, 757, 767, and 777 a royal flush. Boeing has a record of prudently implementing technology while maintaining sound business fundamentals. It won't sell aircraft below cost, whereas Airbus has nearly given away aircraft to boost its order numbers. Boeing continues to focus on technical feasibility and economic viability. It dropped the Sonic Cruiser because of the economics involved, not because of technical issues. Boeing may have been bluffing with the Sonic Cruiser, using it as a distraction when it had a whole new line of aircraft up its sleeve. This gambit allowed Boeing to reveal the 7E7 now that Airbus is betting on the A380. And Boeing's new family of aircraft could make the A380 obsolete. Boeing also continues to make the most advanced military aircraft in the world. The company might be better at poker than you give it credit for.

Frank Ketcham
Sausalito, CA

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HONING LOCATION SKILLS

YOUR STORY "WHEREWARE" (*TR* SEPtember 2003) was one of the most well-rounded articles on the subject I have read. There is one issue that I find present in a number of technological advances: the dumbing of our population. If we throw away our maps, or at least the ability to read them, and need a device to tell us where the next burger place is, what happens when the batteries die, the power goes out, or a big storm takes the servers down? It's not the technology that worries me; it is our unbelievable desire to give up simple skills and just depend on the equipment. If we want to make the future really bright, we need to address the human part of the equation.

A. V. Rutter
Tulsa, OK

OPERATING-ROOM EFFICIENCY

AS AN ANESTHESIOLOGIST, I WAS pleased to see that the Massachusetts General Hospital is trying to improve efficiency in the operating room ("O.R. of the Future," *TR* September 2003) and presumably reduce the sky-high costs associated with surgery. It seems like they are reinventing the wheel with the "new" use of parallel workflow in adjoining rooms. Using a separate room for anesthesia setup has been commonplace in many countries for decades. In Melbourne, Australia, there are areas adjoining each operating room for anesthesia setup, for sterile setup, and for dictation and computer use so the O.R. (and surgeon's) time is used efficiently for operating. When surgeons are kept busy operating there's no need to tag them to find out where they are.

James Mitchell
University of California, San Francisco
San Francisco, CA

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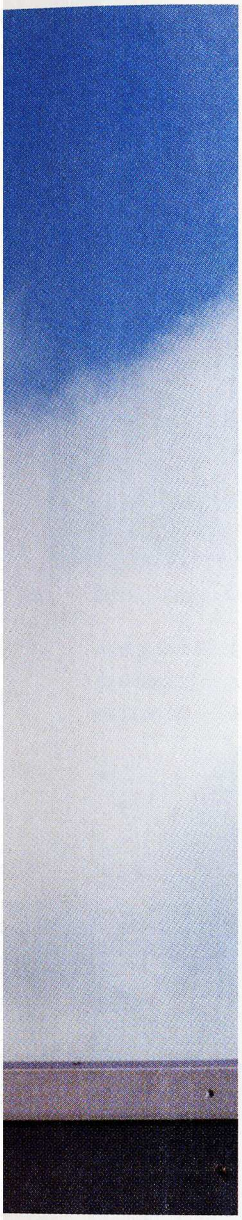
HYBRID SYNERGY DRIVE

TODAY TOMORROW TOYOTA

This is not a drill. A recent study identified financial statistics, R&D data, strategic plans and customer lists as the top information items stolen from companies. Why? Because the more this information empowers you, the more valuable it becomes. Unprotected, it makes a juicy target. But even random attacks can cost you. The Radicati Group says malicious code will cause over $57B in economic damage by 2006. The answer? Security solutions that work inside, outside and end to end.

"Can I see some ID please?"



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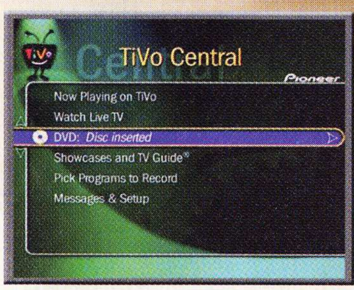

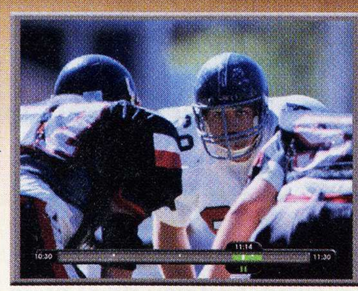

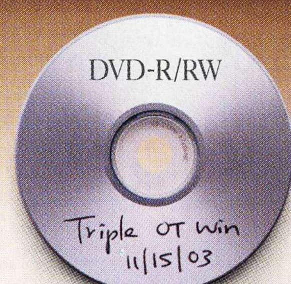

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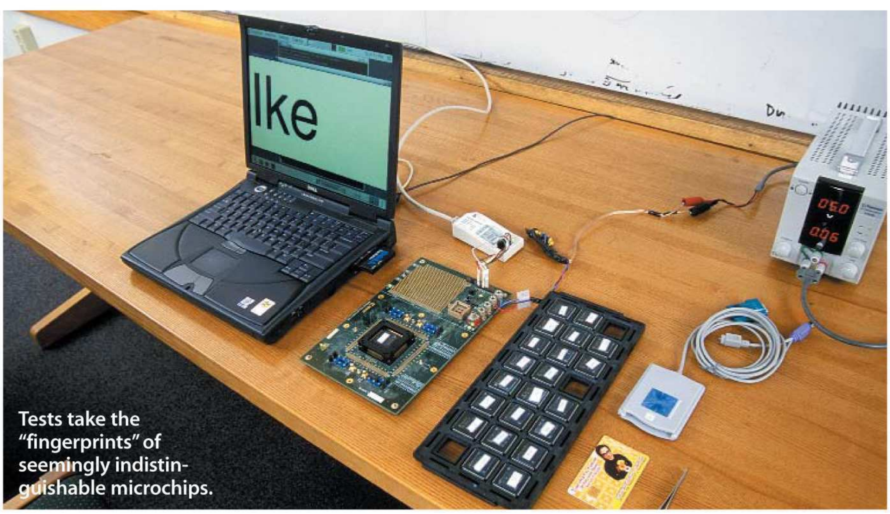
VIDEOCONFERENCING BY THE NUMBERS

USING TODAY'S VIDEOCONFERENCING TECHNOLOGY TO LINK MORE THAN THREE or four remote sites can be prohibitively expensive. But physicists from Caltech have devised a method that enables people located at as many as 40 sites around the world to confer affordably. The new setup employs a network of servers, scattered across 27 countries, that brings people together from different sites in one "virtual room" on the Internet. This approach eliminates the expensive hardware at each site that conventional systems require; instead, it can use cheap commercial webcams and microphones. It should thus allow some users to join videoconferences who couldn't afford to otherwise. A user simply downloads software written by the Caltech group and logs in to a Web site; each of the other attendees appears in a separate window on the user's desktop. More than 5,000 scientists from 88 countries are already using the system, which a team led by Harvey Newman and Philippe Galvez originally developed as a means of communicating with colleagues. The researchers have recently started up a company, VRVS Global in Pasadena, CA, to commercialize the technology.

Web conferencing lets more people meet.



Tests take the "fingerprints" of seemingly indistinguishable microchips.

IDENTITY ANTITHEFT

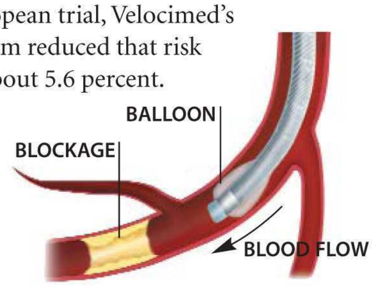
THE MICROCHIPS IN SMART CARDS AND OTHER DEVICES OFTEN STORE DIGITAL keys—long strings of *0*s and *1*s—used to authenticate users and encrypt data in secure transactions. But specialists know that pirates can steal the keys by analyzing the chips' hard-wired connections. MIT computer science professor Srini Devadas might have found a virtually unbreakable scheme: let the chip itself act as the key. At the microscopic scale, circuits are never identical, even on chips manufactured the exact same way, and signals take different times to propagate through silicon and metal paths. Devadas has designed a very simple chip that includes a huge number of paths and a circuit that acts as a stopwatch. By timing the delays along a few hundred of the paths, Devadas can generate a unique fingerprint for each apparently identical chip. That fingerprint—recorded when the chip is made and stored in a database—can act as a key to, for instance, unlock proprietary software, or authenticate an online transaction. Devadas says the secure chip would cost about as much as those used in smart cards but offer much higher security. He and his coworkers have filed a patent and are in discussions with electronic-products manufacturers and smart-card companies about production of the chip, which could be on the market in one to two years.

DIGITAL DOORMAN

Electronic door locks secure everything from offices to dormitories, but wiring them up to send and receive data can be expensive. So Cambridge, MA-based CoreStreet has developed a wireless identity verification system, due out by year's end. Current systems use wires to gain secure access to a central database. But with CoreStreet's system, authorization information is stored at each lock. To periodically update that information, the system uses proprietary algorithms to generate a tiny, encrypted wireless message that informs each lock who has permission to enter. By eliminating wiring, says Phil Libin, CoreStreet's cofounder and president, the system "allows you to control access to things you can't right now," including airplane cockpits and trucks transporting hazardous cargo.

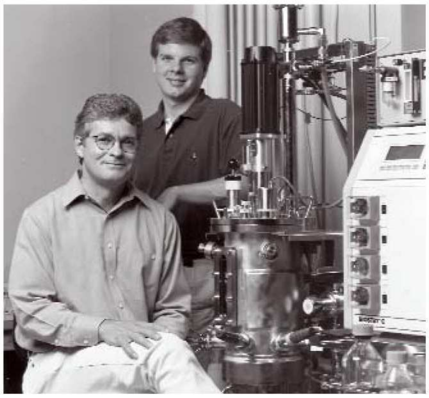
HEART HELPER

OPENING CLOGGED ARTERIES WITH balloon angioplasty saves many heart patients' lives, but the procedure has its own risks. During surgery, bits of the gunk blocking the blood vessel may break off and can cause heart attacks. Velocimed of Minneapolis, MN, is seeking U.S. Food and Drug Administration approval for a system that could reduce that danger. In the system, the artery-opening balloon is inflated upstream of the blockage, so even if gunk breaks off, there's no moving blood to carry it downstream. The trick is a tunnel through the balloon that lets doctors insert a "stent" that props the artery open and suck out any loose material with a syringe before they remove the balloon. With traditional angioplasty, up to 16.5 percent of patients suffer cardiac events such as heart attacks within 30 days of stent placement. But in a small European trial, Velocimed's system reduced that risk to about 5.6 percent.



This artery opener reduces angioplasty's risks.

COURTESY OF VELOCIMED (HEART); COURTESY OF SRINI DEVADAS (IDENTITY); COURTESY OF PHILIPPE GALVEZ (VIDEOCONFERENCING)


Protein makers Jim Swartz and Jim Zawada.

CELL-FREE PROTEINS

PROTEIN-BASED DRUGS ARE A FAST-GROWING CLASS OF NEW MEDICINES, BUT they cost 20 to 100 times more to make than conventional drugs. One reason is that proteins can only be made by living cells, which are not very efficient producers. Researchers at Stanford University believe they can cut costs by doing away with the cells and instead exploiting the protein-making machinery inside them. Chemical engineer Jim Swartz and his colleagues have come up with a way of growing bacteria, busting them open, pulling out their innards, and adding a soup of chemicals that mimics the inside of a cell. Also tossed into the mix are amino acids (proteins' building blocks), enzymes, and strands of DNA that encode the protein to be churned out. With no cells to keep alive, all those parameters can be fine-tuned for protein production. Swartz says the method can boost protein production five- to 10-fold and cut up to 80 percent of the capital costs. The researchers founded Fundamental Applied Biology in San Francisco, CA, to commercialize the technique.


With a swipe of this device, you can print directly onto e-paper.

E-PAPER PRINTER

ELECTRONIC PAPER, MADE OF CHARGE-SENSITIVE "INK" PARTICLES EMBEDDED in a thin plastic film, promises lightweight, flexible displays that consume minimal battery power. But e-paper has typically required a layer of electronics behind the film to turn the particles on and off, adding bulk and cost. Now researchers at the Palo Alto Research Center have developed a handheld device that can print information from a computer directly onto e-paper; the device activates the ink particles electrostatically as it's swiped across the paper's surface. PARC researchers plan to use the device initially to print on large e-paper whiteboards. In the future, the device could also be used to scan information from the whiteboard into a computer. "The idea of a scanning wand in conjunction with electronic paper is a really important step," says Nicholas Sheridon, electronic-paper pioneer and research director at Ann Arbor, MI-based PARC spinoff Gyricon. PARC has multiple patents pending on the technology.

PROGRAMMABLE WINDOW

A huge electronic display on a skyscraper facade can be interesting to passing pedestrians, but if you're inside the building it simply blocks your view. Researchers at MIT's Media Laboratory and Department of Urban Studies and Planning are developing a transparent display that doesn't entirely block incoming light. The group is adapting a commercially available film used in electronic window shades, a high-tech alternative to blinds or curtains that lightens and darkens when electricity is applied and removed. The display will be a matrix of small separate pieces of the film. A grid of tiny wires will connect the pieces to a computer, which will be able to compose letters and figures in grayscale patterns. Because the film at its darkest blocks only 40 percent of incoming light, and because only some of the pieces in the matrix will be darkened at any given time, people sitting behind the display will still be able to see out. Project coordinator Carlo Ratti says the technology might be seen on the streets within a year.

CURVY SECURITY

TO KEEP MESSAGES SECURE, THE COMPUTERS THAT RUN wireless networks must do some complicated math to authenticate every Internet-enabled cell phone or wireless personal digital assistant that contacts them, and the devices must do the reverse, which can tax their batteries. Sun Microsystems senior staff engineer Hans Eberle and his team at Sun Labs are addressing that problem by creating a microprocessor that can be plugged into network computers to quickly authenticate messages from a range of wireless gadgets. The numerical "keys" used to authenticate most electronic messages today are generated by multiplying prime numbers; but to foil hackers, these numbers must be very large, containing up to 1,024 digital bits. Eberle uses a technique called elliptic-curve cryptography that instead derives keys from complex geometrical curves. The complexity of the curves makes the keys more difficult to break, so the same level of security can be achieved with smaller keys that require less computation to use. Eberle's chips can establish secure connections at the rate of 7,000 per second—the "fastest reported," he says. Sun's product groups are evaluating the microprocessors for inclusion in the firm's server computers.


Sun's chip (big black square) secures messages.

COURTESY OF SUN MICROSYSTEMS (CURVY); COURTESY OF THE PALO ALTO RESEARCH CENTER (E-PAPER); COURTESY OF JIM SWARTZ (CELL-FREE)

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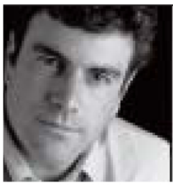
Little Bang for the RFID Buck



RFID TAG; YOU'RE NOT IT. THE ASPIRING "BAR code of the future," midwifed at MIT's Auto-ID Center, faces a serious identity crisis. Proponents insist the tiny tracking tags (RFID stands for radio frequency identification) will profitably transform the global economics of supply chains and customer relationships. Outraged privacy activists attack the diminutive digital devices as Orwellian bugs for tomorrow's surveillance society. Though these rival claims are less about honesty than hyperbole, radio frequency ID is emerging as a symbol of innovation that benefits innovators at the direct expense of consumers. That's bad news for a technology bidding to be a ubiquitous global standard.

Even worse news was Wal-Mart's surprise summertime declaration that it would indefinitely delay a high-profile "smart shelves" RFID test with Gillette. When the world's largest—and most technologically invested—retailer postpones experimentation with a next-generation innovation, that's a market signal radio-tag innovators can't afford to ignore. If any company is superbly positioned to turn a technical protocol into a ubiquitous presence, it's Wal-Mart.

Mere weeks later, another Gillette smart-shelves experiment with Tesco, Great Britain's tech-savviest retailer, ended amid controversy. What's going on here? Are the anti-radio-tag activists winning the privacy propaganda wars? Does RFID technology promise more than it can reasonably deliver? Or do the darn tags simply cost too much?

The answer reveals a great deal about the dueling economics—and dueling ethics—of innovators with conflicting business models. Technology innovators must always remember that there's a huge difference between customers who invest in innovation to *save* money and those who invest to *make* money. The fervent belief that saving money and making money are somehow equivalent is the great innovation delusion.

There's a difference between investing in innovation to *save* money and investing in innovation to *make* money.

Wal-Mart has no such delusions. At the same time that the retailing behemoth canceled its in-store test, it reiterated its intent to push suppliers to attach radio tags to all the cases and pallets they ship to the company's warehouses. Why? Because even a casual back-of-the-envelope analysis shows Wal-Mart getting by far the biggest bang for its RFID buck from using the tags to boost efficiencies within its gargantuan logistics infrastructure.

In other words, Wal-Mart best maximizes its ROR—Return on RFID—*not* by using smart tags to better track millions of customers spending billions of dollars but by optimizing the processes that place hundreds of thousands of products on its shelves. Wal-Mart's ability to deliver on its "everyday low prices" promise depends more on rigorously tracking products than rigorously—intrusively? invasively?—monitoring customer purchases. Wal-Mart knows this. So do its suppliers. And so the Auto-ID Center is learning.

But what about *making* money through radio-tag tracking? Don't retailers like Tesco—with business models and investor expectations geared to higher margins than Wal-Mart's—also have a big incentive to go beyond internal supply chain efficiencies? Yes, but the barrier is obvious: the economics of the tags are inherently different when they're employed to increase customer value rather than cut internal costs. Whether the tags cost a penny, a nickel, or a dollar is irrelevant to the essential business question: how are they used to add value—genuine or perceived—for customers?

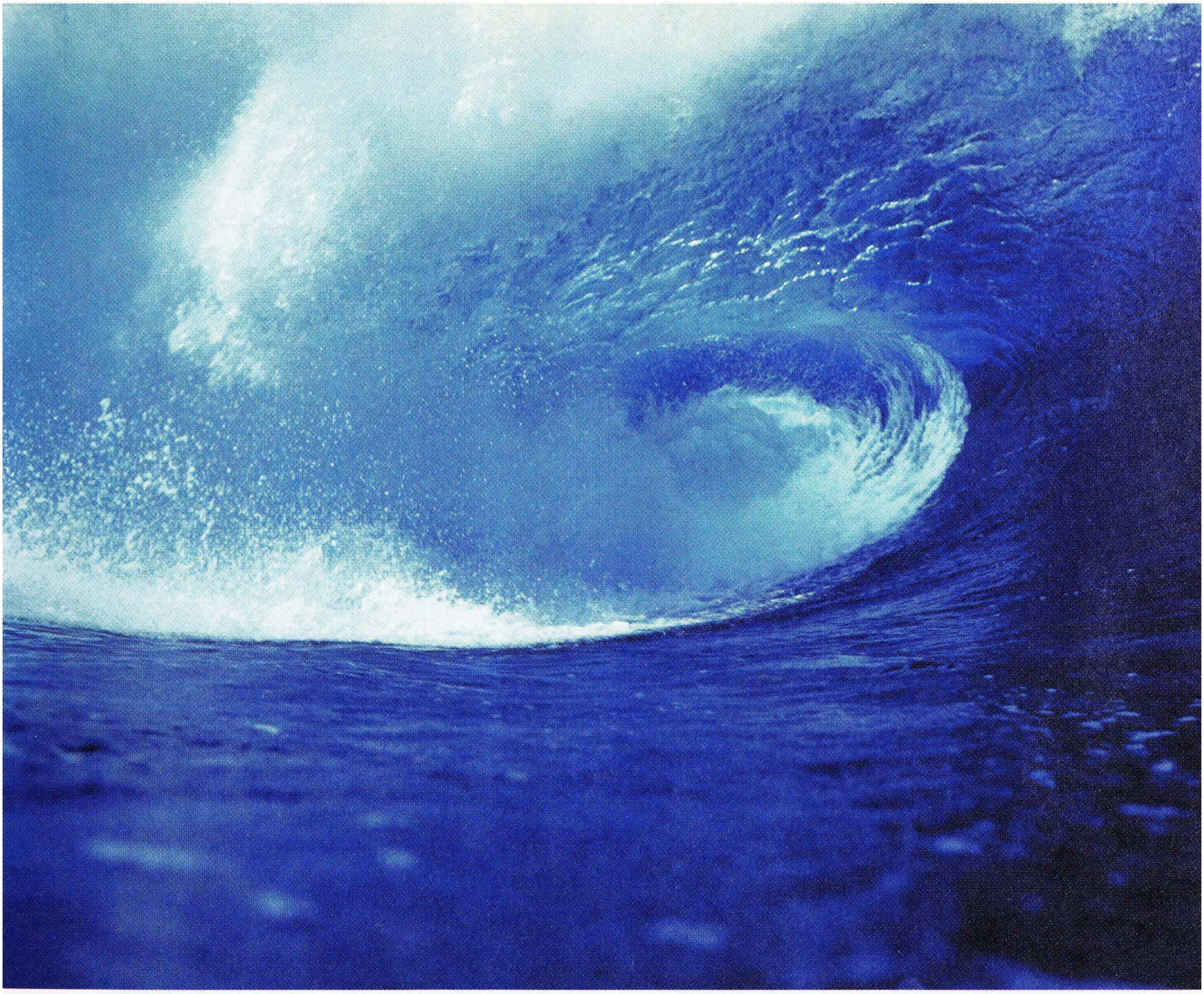
Apparently, neither retailers nor manufacturers have yet figured out an economically intelligent answer. Even worse, RFID champions appear unable to design real-world business experiments that potential customers find more exciting than offensive. In effect, radio tags have everything to do with cost reduction and nothing to do with value creation. The issue isn't RFID technology; it's determining how to persuade customers that an innovation's benefits unambiguously outweigh its costs.

Indeed, the loudly debated privacy issue is a red herring. The RFID community could take its cue from the credit card companies who monitor customer purchases in real time. Visa, MasterCard, and American Express have convinced millions of their customers that real-time monitoring cuts back on fraud and the risk of identity theft. In other words, the costs of privacy invasion are outweighed by the benefits of increased security.

The problem with radio frequency ID is that it's clear how retailers and manufacturers might benefit from attaching smart tags to their products, but it's utterly unclear how this helps consumers.

The moral of this ongoing tagging tale is simple: everyone understands "everyday low prices." But if customers can't see how they'll get value from your proposed innovation, the problem is not their ignorance but your own. TR

Michael Schrage **is a consultant and researcher who writes widely about innovation.**



Cancer warrior: Dendritic cells like the one in this colorized image are modified in the lab, then injected into the patient to spur an antitumor immune response.

Booster Shot against Cancer

Cautious optimism about the latest efforts to enlist the immune system. **BY CORIE LOK**

IN THE WAR ON CANCER, researchers have long struggled to recruit the body's immune system to attack tumors while leaving healthy cells alone. This strategy—basically that of vaccination—would offer a huge improvement over existing treatments such as chemotherapy and radiation, which kill healthy and diseased cells indiscriminately and carry harsh side effects. But repeated attempts to find a cancer vaccine have failed, largely because scientists have had a crude understanding of the molecular mechanics of the immune system and cancer cells.

Today, armed with a growing understanding of how to manipulate the immune system, researchers are offering the glimmer of a hope that cancer vaccines could soon become part of the cancer-fighting arsenal. More than 50 cancer vaccines are being tested in the United States, Canada, and Europe against several types of cancers, including melanoma and kidney, lung, breast, and prostate cancers. Several are in the final stages of human trials, at least two of which are expected to conclude within a year. In some of the trials, a few patients have seen their cancers go into remission, while in other patients, the vaccine slowed the spread of the disease. If all goes well, the first cancer vaccine could be ready for general use in three to five years.

"We are learning more and more about how to turn on the immune system and how to regulate it to get an antitumor effect. That's why we have so many potential new vaccines being pursued," says Antoni Ribas, an oncologist developing a melanoma vaccine at the University of California, Los Angeles.

Cancer vaccines, unlike conventional vaccines, are designed not to prevent disease but rather to treat it. The immune system is normally relatively

COURTESY OF DENDREON

tolerant of cancer, and the trick is to get it to see tumors as the enemy. Approaches include manipulating tumor proteins and specialized immune cells in the lab, so that when they are put back into the body, they "teach" the immune system to see the tumors as foreign. Earlier attempts at cancer vaccines often used whole tumor cells, which present a mixed bag of unknown proteins to the immune system. Newer vaccines use a smaller number of extracted and purified proteins, which some researchers say promise to be more effective and predictable.

So far, successes have been modest but promising. One of the efforts that's gone farthest is a prostate cancer vaccine from Dendreon of Seattle, WA. In one trial, researchers found that a subset of patients with less aggressive tumors went a median of seven weeks longer than untreated patients before the disease progressed. A second trial focusing only on patients with less aggressive tumors is under way. If results are favorable, the company expects to file for regulatory approval with the U.S. Food and Drug Administration by late next year. Another company, Antigenics of New York City, is now conducting the final stage of human trials of kidney cancer and melanoma vaccines. The company expects initial results from the kidney cancer trial later this year.

At their most optimistic, of course, cancer researchers hope the new vaccines will stop and shrink tumors. That has happened in a few isolated cases in some trials involving melanoma and kidney cancers. But more likely is that these new vaccines will be part of a larger treatment strategy, a way to mop up cancer cells after surgery or chemotherapy, or to reduce the need for chemotherapy or radiation in the first place.

In this respect, vaccines are seen as the next up-and-coming cancer therapy, following a group of drugs that use proteins called monoclonal antibodies. Monoclonal-antibody drugs, six of which have made it to market, bind specifically to cancer cells and either slow down their growth or mark them for destruction by the immune system. But patients have to take the drugs continuously, and they're expensive.

With a vaccine, by contrast, patients would in theory only have to get a few shots; their own immune systems would do the rest. David Urdal, president and chief scientific officer of Dendreon, says cancer vaccines today are where monoclonal antibodies were ten years ago. "We're now at that threshold with the cancer vaccine," he says.

Some recent cancer vaccines have proved disappointing, however. A breast cancer vaccine from Biomira in Edmonton, Alberta, failed recently in advanced trials. And although a melanoma vaccine from Corixa of Seattle is approved in Canada, the FDA said approval in the U.S. would require a second trial, which Corixa may or may not attempt.

If other cancer vaccines work better, they might still pose problems. Vaccines could prime the immune system to go after not only cancer cells but also healthy ones. And some vaccine strategies require the isolation and purification of immune cells or tumor proteins from individual patients, which may make the treatments prohibitively expensive and labor intensive. But perhaps most worrisome is that, as vaccine developers well know, cancer cells are cunning creatures. "They have a lot of escape mechanisms to overcome obstacles generated by a vaccine," said Steven Rosenberg, a researcher at the National Cancer Institute in Bethesda, MD, who is testing vaccines and other ways of recruiting the immune system to fight cancer.

And even proponents say cancer vaccines probably won't be enough to fight cancer alone. Vaccines would have to work in combination with other therapies, bombarding tumors from all sides. Still, after decades of frustrated research efforts, recent advances are raising cautious hopes that these new therapies will soon take their place in the cancer-fighting arsenal. TR

Vaccine hope: Late-stage melanoma (left) was in remission (right) for 32 months after treatment with an experimental cancer vaccine.

COURTESY OF ANTIGENICS

CANCER VACCINE PIPELINE

COMPANY	KEY TO VACCINE	STATUS
Antigenics (New York, NY)	Proteins isolated from patient's tumor	Kidney cancer vaccine late in phase III trials, with results expected next year; melanoma vaccine in early phase III trials
CancerVax (Carlsbad, CA)	Whole tumor cells	Melanoma vaccine in phase III trials
Cell Genesys (South San Francisco, CA)	Genetically modified tumor cells	Prostate cancer, lung cancer, pancreatic cancer, and leukemia vaccines in phase III trials
Corixa (Seattle, WA), **GlaxoSmithKline Biologicals** (Rixensart, Belgium)	Tumor protein or DNA	Lung and breast cancer vaccines in phase I trials
Dendreon (Seattle, WA)	Specialized immune cells from the patient activated outside the body	Prostate cancer trial late in phase III, with results expected next year
Progenics Pharmaceuticals (Tarrytown, NY)	Carbohydrates and proteins found on tumors	Two melanoma trials: one in late phase III, the other in early phase III; prostate cancer vaccine in phase I

HARDWARE

Just Tilt to Enter Text

THE SAME TINY GIZMOS THAT DEPLOY AIR BAGS IN cars could soon make cell phones less cumbersome to use. Several academic and corporate labs are developing ways to use ultrasmall accelerometers and gyroscopes—which sense a car's sudden deceleration during a crash and trigger the air bags—in the guts of cell phones and other handheld devices. This makes common tasks, such as scrolling through lists, entering numbers, and moving information from one place to another, much easier; you simply tilt the gadget in various directions.

In July, MyOrigo of Oulu, Finland, released the first motion-sensitive Web-enabled cell phone. If only part of a Web page fits on the screen, tilt the phone toward the missing content and it slides into view. It's a novel approach that "gets at one of the core problems of navigating a Web page on a mobile device," says Kevin Burden, an analyst at IDC in Framingham, MA.

A motion-sensing phone changes display orientation.

Other researchers are using tiny accelerometers to allow simpler text entry on handheld devices. Ravin Balakrishnan and Daniel Wigdor, University of Toronto computer scientists, have built a prototype cell phone in which, for example, tapping the "7" key while tilting the phone forward enters the letter *q* on the display screen, but tilting to the right enters the letter *r*. In tests, Wigdor and Balakrishnan found that subjects using the device could enter text 30 percent faster than they could through the usual approach, in which a user taps a number key multiple times to select one of the three letters written on it. The researchers say several manufacturers have expressed interest.

The next step for accelerometers? Ken Hinckley, a Microsoft researcher, envisions handhelds that form instant wireless connections when clinked together like champagne glasses. Hinckley prototyped the idea using Wi-Fi-enabled tablet computers with embedded accelerometers. Bumping two tablets establishes a connection: if one tablet reports moving leftward and striking another object, and the other reports a bump on its right side at exactly the same time, both know that they have been linked. Tilting one of the tablets then dumps the contents of an open window—again via Wi-Fi—onto the other's desktop. Microsoft doesn't have any immediate market plans, but Hinckley is already talking about putting the same functions into wristwatches. And that could let you send files just by shaking hands. —*Larry Hardesty*

SOFTWARE

Digital Darwin

It's a jungle out there. So businesses of every kind are increasingly turning to software rooted in survival-of–the-fittest strategies to solve extraordinarily complex problems like managing air traffic, optimizing the efficiency of service calls, and even creating new materials and food flavors.

Software based on so-called genetic algorithms is "showing up in every way, shape, and form" in the business world, says Stephanie Forrest, a professor of computer science at the University of New Mexico. Genetic algorithms create a group of solutions to a particular problem—say, how to reschedule a fleet of airplanes when a thunderstorm shuts down a major airport. The algorithms rapidly replicate, mutate, and produce new generations of possible solutions that yield better and better results, all with very little human intervention. Millions of solutions might be created, but like fish eggs drifting in the sea, most will die. A solution that is better than its competitors eventually emerges.

It's an approach that has been kicking around academic circles for years and has yielded some practical applications, but it is only now finding widespread commercial adoption. "Finally, this technology is coming out of the geeky environment and is being provided as a business solution," says Navi Radjou, a principal analyst at Forrester Research in Cambridge, MA.

The list of businesses using evolutionary software is expanding. For example, Delta Airlines this year signed on with a company that develops genetic algorithms, Ascent Technology of Cambridge, MA, to optimize the schedules of many of its employees—one of the biggest individual jobs ever undertaken by this type of software. Delta's objective is to cut costs without reducing its level of service. And that's a survival strategy that might have impressed Darwin himself. —*Chip Walter*

SAMPLING OF COMPETITORS

COMPANY	TECHNOLOGY
Ascent Technology (Cambridge, MA)	Evolutionary software to optimize airport and airline operations
IBM Research (Hawthorne, NY)	Large-scale, self-managing, self-repairing computer systems
NuTech Solutions (Charlotte, NC)	Evolutionary software that competes to solve problems from traffic-light coordination to artificial-flavor development
RDI (London and Cambridge, England)	Evolutionary software to optimize drug combinations for HIV treatment
Tripos (St. Louis, MO)	Genetic algorithms that speed drug development

COURTESY OF MYORIGO


Goodbye
Hackers


Hello
Customers

New sculpted blades, composite materials, and sheer size—its diameter is almost that of a Boeing 737's fuselage—help make this GE engine the world's most powerful for a commercial jet.

TRANSPORTATION

Souped-Up Jet Engine

SOMETIME THIS COMING SPRING, airline passengers will be propelled aloft by a jet engine that sets a new record as the world's most powerful. Packing some 52,000 kilograms of thrust—enough that just two engines could carry 365 passengers in a beefed-up Boeing 777 halfway around the world—the $21 million mammoth engine from General Electric is 22 percent more powerful than the previous-generation GE engine.

It's designed to help Boeing beat back rival Airbus, the European aircraft consortium. In 2006, Toulouse, France-based Airbus is expected to begin delivering a new jet called the A380, which can carry 555 passengers. This superjumbo jet is presenting a serious threat to the Boeing 747 jumbo jet. As part of its response *(see "Boeing's Flight for Survival," TR September 2003)*, Chicago-based Boeing decided to soup up its 777 to carry more weight and fly farther—even the 16,700 kilometers of the world's longest route, from Singapore to Los Angeles. But because the 777 has two engines, compared to the A380's four, it needs more power per engine to carry so much weight over such distances.

Chaker Chahrour, general manager of the program to develop the new engine at GE Aircraft Engines in Cincinnati, OH, says GE enlarged and increased the efficiency of an existing GE engine by adding new sculpted contours to its fan blades, which are made of lightweight composite materials. The new blade scoops up more air and increases pressure inside the engine, which adds thrust.

Increased size helps, too: the blade assembly is 325 centimeters in diameter, almost the same diameter as the entire fuselage of a Boeing 737. To prevent dangerous imbalances should a blade shear off in flight, GE engineers designed a way for the fan to disconnect from the main shaft so it would stop spinning in seconds. (The remaining engine can still fly the plane for five and a half hours, long enough to reach a landing field even if the failure occurs mid-Pacific.)

The first people to enjoy the new engine will likely be Airbus's own neighbors: Boeing expects to deliver its first 777 with the new engines to none other than Air France. *—David Talbot*

INTERFACES

Listening to the Data

As any music lover knows, the human ear is adept at picking out subtle patterns. And the growing power of computers to translate almost any kind of information into variations in pitch, rhythm, or volume is boosting the field of sonification, the representation of data as sound. From sounding out variations on a pathologist's tissue section slide to flagging suspicious travel activity, sonification has the potential to help scientists, doctors, and analysts spot trends and trouble spots.

Ronald Coifman, a mathematician at Yale University, and Jonathan Berger, a composer at Stanford University, have developed software that transforms light reflected off colon cells under a microscope into pulsating sounds. Under one setting, cancerous cells are louder than healthy ones. Coifman and Berger's study is mainly aimed at discovering which sound patterns are most effective at conveying complex data, which Coifman says they and other researchers will achieve in two years.

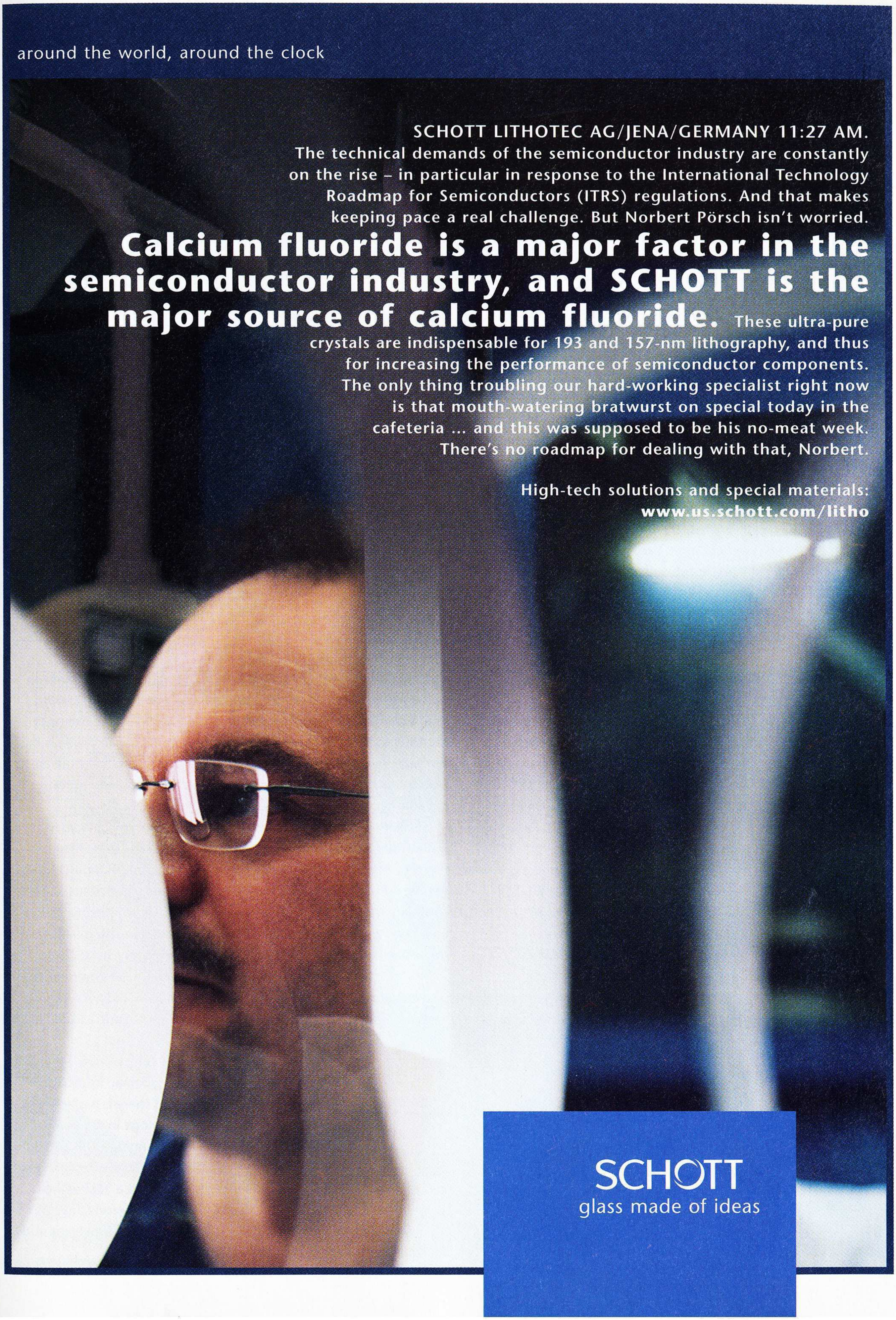
Also listening are U.S. counterterrorism investigators. Cynthia Traeger, CEO of Visual Synthesis in Fairfax, VA, says her software company is in discussions with the U.S. Department of Defense about using sonification to find evidence of terrorist activity in databases. "A complex network of connections becomes a symphony," explains Traeger. If such applications work, the resulting buzz won't be hard to hear. *—Wade Roush*

THE SOUND OF CANCER

What does the stock market or a cancerous colon cell sound like? Sample sound files are available at this Stanford University Web page:

www-ccrma.stanford.edu/groups/soni/sounds.html

COURTESY OF GE AIRCRAFT ENGINES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The technical demands of the semiconductor industry are constantly on the rise – in particular in response to the International Technology Roadmap for Semiconductors (ITRS) regulations. And that makes keeping pace a real challenge. But Norbert Pörsch isn't worried.
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SENSORS

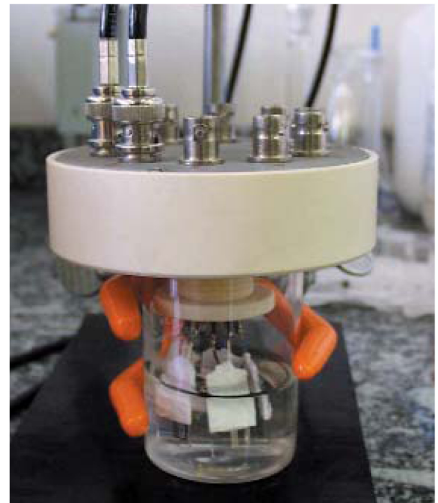
Banishing Bad Beans

Coffee merchants rely on human tasters to ensure that the $70 billion worth of coffee sold every year has consistent flavor. Now, this job is being given to automated technology, and it's happening in the country that produces more coffee than any other.

An "electronic tongue" perfected by Brazil's agricultural research agency Embrapa is poised to begin the mass tasting. Based on technology developed at the University of Pennsylvania, it consists of 10 gold electrodes covered by thin films of an electrically conducting polymer. Each film contains a different mix of organic and inorganic compounds that are sensitive to molecules responsible for characteristics like bitterness, sourness, and acidity—and even levels of caffeine. Various molecules in liquid samples of coffee are absorbed by these thin films, changing the electrical properties of the electrodes and providing taste signatures.

Beginning next year, labs throughout Brazil will use the device to test coffee sold domestically. Later, coffee manufacturers could select a flavor benchmark for subsequent real-time evaluation on the production line. "The electronic tongue is an invaluable tool to improve the quality of coffee sold to consumers," says Nathan Herszkowicz, executive director of the Brazilian Coffee Roasters Association.

Other electronic sensors can distinguish among basic tastes—for example, the sourness of milk or the bitterness of medicine—but they cannot always detect the subtle variations in coffee and other beverages. "Our electronic tongue will cost half of the price and will be about 1,000 times more sensitive than others available," says Luiz Henrique Mattoso, a materials scientist who led the Embrapa project. With any luck, bad beans won't make it into your mug. —*Erico Guizzo*



Conducting polymer sensors, shown immersed in liquid, detect key flavor characteristics.

MEDICINE

Drug Patches Advance

For the millions of diabetics and other patients who need to self-inject drugs daily with painful needles, reliable skin patch devices—similar to the ones ex-smokers use to get their nicotine fix—would be a great relief. The trick is finding ways to push large-molecule drugs, like insulin and human growth hormone, through the skin's oily top layers. An Israeli company believes it has a promising solution: radio waves.

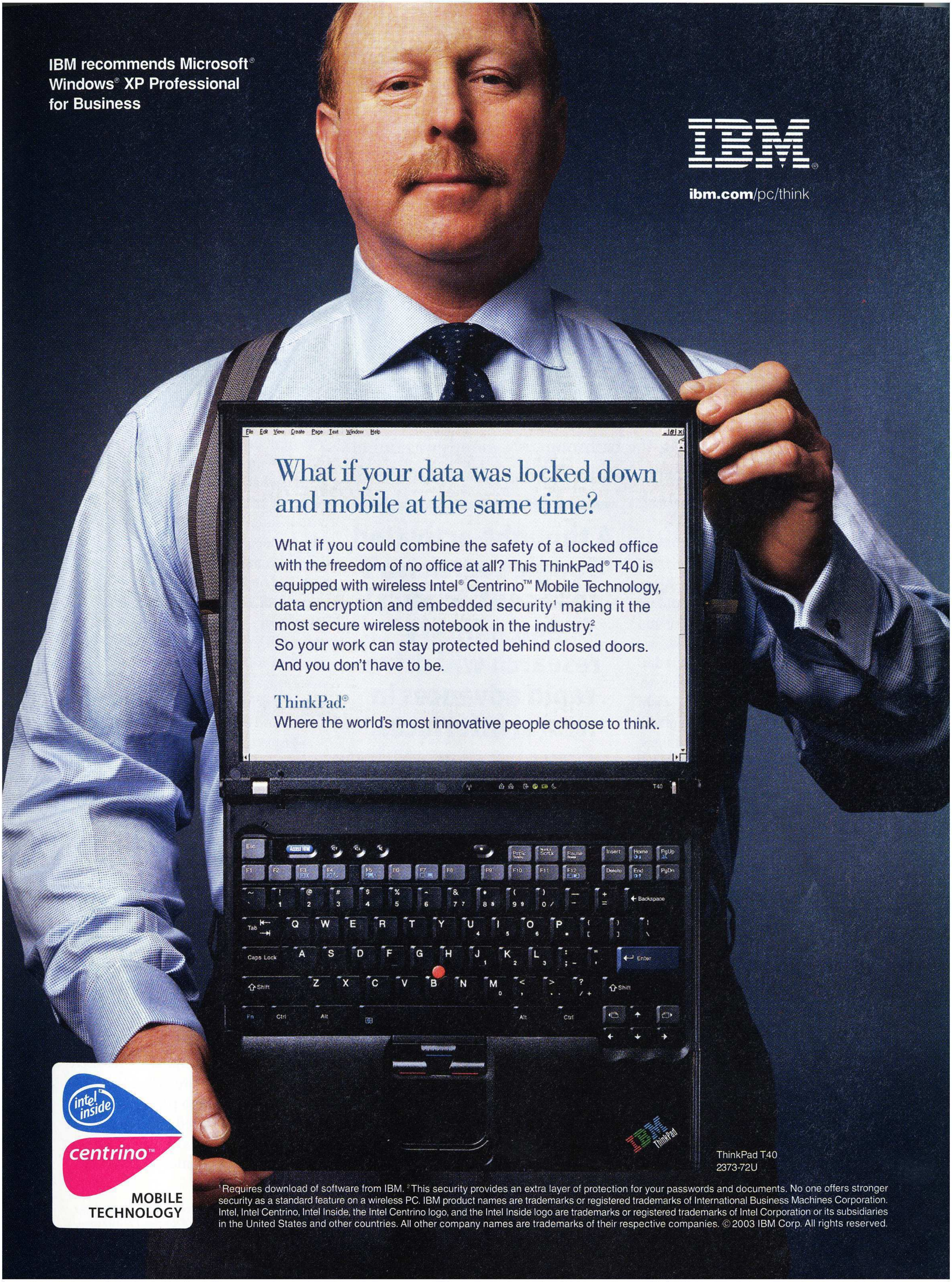
TransPharma Medical of Yehud, Israel, has developed a handheld device that administers a blast of radio frequency energy to scrape away the top layer of skin cells. This produces channels about 50 micrometers wide that allow drugs from a patch to work their way into the bloodstream. "Of the methods used to open up channels through the skin to allow bigger molecules to be delivered, this company's approach sounds the most promising," says Gordon Flynn, professor of pharmaceutical science at the University of Michigan. That's because the device—which has met with success in initial studies—opens pores for a whole day with minimum discomfort, sterilizes them, and adjusts for different skin types, Flynn says.

Still, TransPharma hasn't proven its technology in human trials. Chief executive officer Daphna Heffetz says that within a few months, the company will begin clinical trials of a patch for people suffering from human-growth-hormone deficiencies. The company is conducting studies with four pharmaceutical companies to determine the feasibility of the approach with insulin and other drugs. "It looks interesting, but it is still early stage," says Samir Mitragotri, a chemical engineer at the University of California, Santa Barbara, and a cofounder of Sontra Medical of Franklin, MA.

There's plenty of competition. Sontra, for example, is developing an approach that uses ultrasound. "There is a place for more than one technology in the market. I think each viable technology will find its niche," says Mitragotri. Whichever versions succeed, they could create a $5.7 billion market by 2009 in the U.S. alone, says Ajit Baid, analyst at the research firm Frost and Sullivan. —*Tania Hershman*

LEADING APPROACHES TO THROUGH-THE-SKIN DRUG DELIVERY

COMPANY	TECHNOLOGY	STATUS
Altea Therapeutics (Atlanta, GA)	Electrical pulse that turns to heat to create micropores through skin	Patches for osteoporosis, pain medication, and insulin in preliminary trials
Alza (Mountain View, CA)	Low-level electric current that opens up pores	In final phase of tests for fentanyl, a drug used to treat postoperative pain
Sontra Medical (Franklin, MA)	Ultrasound used to open up pores	In development for growth hormones; pain patches could be ready by 2006
TransPharma Medical (Yehud, Israel)	Radio frequency energy that creates microchannels through the top layer of skin	Preliminary human trials for human growth hormone; feasibility studies with four pharmaceutical companies



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Toward a Brain-Internet Link

A FEW WEEKS AGO I WAS BRUSHING MY TEETH AND trying to remember who made "La Bamba" a big hit back in the late 1950s. I knew the singer had died in a plane crash with Buddy Holly; if I'd been downstairs I would have gone straight to Google. But even if I'd had a spoken-language Internet interface in the bathroom, my mouth was full of toothpaste. I realized that what I really want is an implant in my head, directly coupled into my brain, providing a wireless Internet connection.

In my line of work, an effective brain-computer interface is a perennial vision. But I'm starting to think that by 2020 we might actually have wireless Internet interfaces that ordinary people will feel comfortable having implanted in their heads—just as ordinary people are today comfortable with going to the mall to have laser eye surgery. All the signs—early experimental successes, societal demand for improved health care, and military research thrusts—point in that direction.

A thought-activated Google search isn't so far out. Medical and military research will drive rapid advances in neural interfaces.

Remote-controlled rats are perhaps the most stunning evidence of this trend. Last year, John Chapin and his colleagues at the State University of New York's Downstate Medical Center in Brooklyn reported installing brain implants that stimulate areas of the rat cortex where signals are normally received from the whiskers. Left/right cues from a laptop computer made the rats feel as if their whiskers had brushed into obstacles, prompting them to turn in the appropriate directions. To impel the rats up difficult inclines, a second implant stimulated pleasure centers in their brains.

This experiment built on the 1999 efforts of Chapin and Miguel Nicolelis at Duke University that enabled rats to mentally induce a robot arm to release water. First, a computer recorded the patterns of neural firing in key areas of the rats' brains when the rodents pressed a lever that controlled the robot arm. Once the computer learned the neural pattern associated with lever-pushing, it moved the robot arm when it detected the rats merely "thinking" about doing so. In later versions of this technology, monkeys were able to control a more sophisticated robot arm as though it were their own.

Machine-neuron connections are working in people, too. Thousands of once deaf people can understand conversations thanks to cochlear implants. A tiny microphone in the ear picks up sound, and a small package of electronics translates this into direct stimulation of neurons in the cochlea. More recently, there have been reports of human trials in which comparable (though much more crude and early-stage) visual implants enabled blind patients to perceive something of their surroundings. And a handful of quadriplegic patients have neural implants that let them control computers by "thinking" about moving particular muscles.

Why am I confident that brain-Internet interfaces will become a reality? Because it's not really such a vast leap from here to a thought-activated Google search: these human-tested technologies already give us the components that we would need to directly connect the Internet to a person's brain. And because there are both medical and military pulls on related technologies. On the medical side, besides the urgency of providing physical and mental prostheses to patients with severe injuries, baby boomers are getting older, and their nervous systems are starting to fall apart. There will be increased demand for patching up deteriorating nervous subsystems—and baby boomers have always gotten what they demand. At minimum, this will drive the development of direct visual interfaces that by 2010 will help blind people as much as today's cochlear implants help deaf people.

And on the military side, direct neural control of complex machines is a long-term goal. The U.S. Defense Advanced Research Projects Agency has a brain-machine interface program aimed at creating next-generation wireless interfaces between neural systems and, initially, prosthetics and other biomedical devices.

Just as the modern laptop was inconceivable when the standard computer interface was the punch card, it's hard to imagine how a brain-Internet interface will feel. As brain-imaging technologies continue their rapid advance, we will get a better understanding of where in the brain to insert signals so that they will be meaningful—just as the control signals for the rats were inserted into neurons normally triggered by whiskers.

We still need broad advances, of course. We need algorithms that can track the behavior of brain cells as they adapt to the interface, and we'll need better understanding of brain regions that serve as centers of meaning. But we'll get there. And when we do, we won't "see" an image similar to today's Web pages. Rather, the information contained in a Web server will make us feel as though "Ritchie Valens" just popped into our heads. TR

Rodney Brooks is director of MIT's Computer Science and Artificial Intelligence Laboratory.

WEBB CHAPPELL

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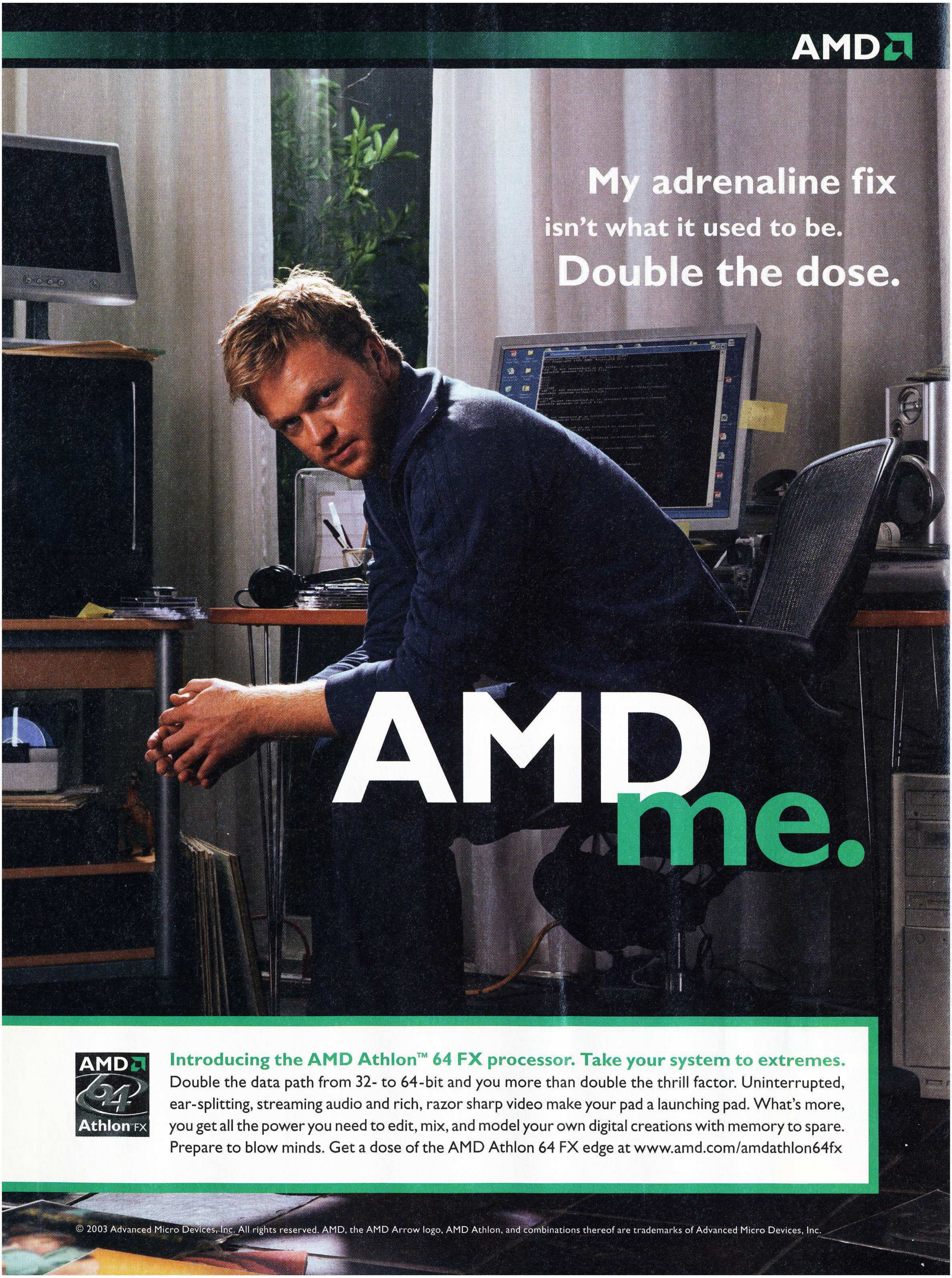

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EXCLUSIVE REPORT

software goes extreme

Charles Simonyi and **Mitch Kapor** invented the software that helped kick-start the PC revolution. Now they're at it again, investing their fortunes in ventures aimed at finally creating programs that do what you want them to and never crash. In a future envisioned by these iconoclasts and a growing body of companies, including IBM and Sun Microsystems, programs repair themselves, and the desktop metaphor is replaced by computer interfaces that put information at your fingertips depending on what job needs doing, not what application you're running. ▪ The days when it was feasible to build a bridge, trade a stock, or prepare a report without software are long gone. But that doesn't mean we have to settle for today's typical applications, which have an infuriating tendency to fail when we need them most. Indeed, it's hard not to share Kapor's view that the average software user "really gets screwed." And once you've read what he and his fellow radicals plan to do about that, you may share their impatience. **Welcome to the new software revolution.**

EXCLUSIVE REPORT

everyone's a programmer

NOBODY—NOT EVEN PROGRAMMERS—SHOULD HAVE TO WORRY ABOUT MAKING EVERY LINE OF A PROGRAM PERFECT. LET'S LEAVE THE BUSYWORK OF SOFTWARE ENGINEERING TO THE MACHINES, SAYS BILLIONAIRE SOFTWARE GURU CHARLES SIMONYI. THEN USERS CAN START TO TAKE CONTROL.

by claire tristram | photograph by julia kuskin

Intentions known: Charles Simonyi became a billionaire by pioneering software. Now he's out to revolutionize programming.

FEW SOFTWARE experts have had as revolutionary an influence on the development of computing as Charles Simonyi, and few have been so richly rewarded for their efforts. As a scientist at Xerox's Palo Alto Research Center in the 1970s, Simonyi invented Bravo, the first word-processing program that showed on-screen exactly how a document would look in print—a concept commonly referred to as "what you see is what you get." Simonyi then joined Microsoft, when it was still a startup with three dozen employees. There he became the company's chief architect, piloting the development of both Word and Excel. Along the way, he also became a billionaire: *Forbes* recently listed him as the 209th richest person in the United States.

Last year Simonyi abruptly ended his 21-year tenure at Microsoft to start a company of his own, Intentional Software, which he has, to date, funded entirely with his own money. In one sense, Intentional Software is a modest company with modest goals; Simonyi does not expect to have a product to sell for several years. But in another sense, his goals are so large that the word "ambition" barely does them justice. Simply put, Simonyi wants to save software from its own complexity—so that the true potential of computer technology can at last be realized.

Grand quests are something Simonyi knows a lot about: he left Hungary to study abroad at the age of 17 and—illegally—never returned. While he still speaks with a faint accent, he also expresses his opinions unequivocally, without any searching for words, especially when talking about his favorite subject.

Software "has become a field where we focus on incremental improvements in processes," he says. "That course is futile, because it can never solve the problem of human imperfection."

What Simonyi proposes instead is a revolutionary change in how we write software, and even in how we *think* about software. "Conventional improvements people make come at the expense of forgetting what software is all about," he says.

Why does software need a revolutionary change? Because today it is a technology in crisis, where its complexity has far outrun our ability to comprehend it. It's next to impossible to understand what is going on in software whenever a program runs longer than a few hundred lines of code—and today's desktop software contains millions of lines. What we don't understand, we can't fix: 25 percent of commercial software projects are canceled, which meant $60 billion in losses in 2000 in the U.S. economy alone *(see "Why Software Is So Bad,"* TR *July/August 2002)*.

Even as software collapses under the weight of its own complexity, we've barely begun to exploit its potential to solve problems. The challenge, Simonyi believes, is to find a way to write programs that both programmers and users can actually read and comprehend. Simonyi's solution? To create programming tools that are so simple and powerful that the software nearly writes itself—in much the way that Excel automatically adds columns of numbers or Word automatically formats our documents.

"Software should be as easy to edit as a PowerPoint presentation," Simonyi asserts. That means giving it just as intuitive an interface.

MARK GILBERT

Software needs to keep pace wi

Simonyi is attempting to solve one of the most fundamental problems of software development, typically expressed as "making the code look like the design." If he succeeds, users will be able to create high-level designs of what they want their programs to do, which might resemble flow charts more than lines and lines of code. From these designs, code will be created automatically.

As the inventor of the first what-you-see-is-what-you-get interface, Simonyi seems uniquely suited to this challenge. But it's still a tall order. Some say it can't be done: people have been trying to create representative models that could automatically generate complex code for about as long as they

Everyday software: Gregor Kiczales, who started Intentional Software with Simonyi, has long worked to simplify code writing.

th hardware, and the way we write code today, it just won't.

have been writing software, and they have achieved only the most rudimentary successes.

Others say we have no choice. Indeed, similar if less extreme efforts to simplify and automate the task of programming are under way at IBM, Sun Microsystems, and other industrial and academic institutions *(see "Writing Software Right,"* TR *April 2003).*

"We are trying to solve ever more complex problems with software," says Grady Booch, a friend of Simonyi and one of the inventors of the Unified Modeling Language. Like the approach Simonyi proposes, this software language allows programmers to reason about what software should do without having to worry about details at the level of the actual code, whether it's written in Java, C++, or one of today's other common languages. Last December, IBM spent $2.1 billion to acquire Rational Software, the company where Booch and his colleagues developed the Unified Modeling Language.

"If you take a look at where we are going," says Booch, citing emerging technologies such as nanoscale microprocessors, which should make computers vastly more powerful, if only we can find effective ways to write software for them, "you see there is no end state." In other words, he insists, software needs to keep up with hardware, and the way we write it today, it won't.

UNBURYING INTENTION

How do you make the code look like the design? First, Simonyi contends, you have to understand what's wrong with the current practice of programming.

"Programming today is the opposite of diamond mining," he claims. "In diamond mining you dig up a lot of dirt to find a small bit of value. With programming you start with the value, the real intention, and bury it in a bunch of dirt."

In Simonyi's view, software developers are doomed to fail because they need to do three jobs at the same time—only one of which they are well suited for. First, they have to understand the often complex needs of the client—the insurance specialists or accountants or aircraft designers for whom the software is being built. Programmers must try to soak up knowledge that their clients have spent years accumulating. If not a wholly impossible task, it's certainly an inefficient use of their expertise.

Second, programmers must translate these client needs into algorithms and interfaces that the computer system can understand. Simonyi sees this as the core task of the programmer. But today it's done poorly: when the programmer has completed the software, there is no way for clients to modify it or even to understand how it reflects their contributions.

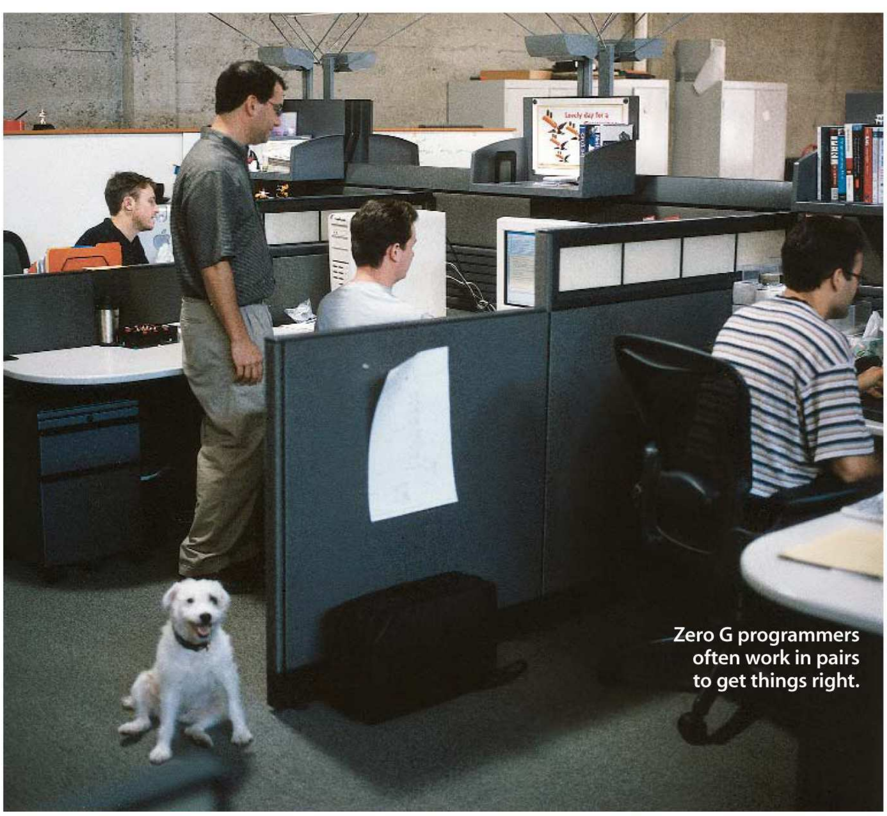
Third, in order for the computer to execute instructions properly, programmers must write perfect code—with the precision of a machine. Despite constant claims from software companies about the superiority of their development processes to their competitors', the fact is that bug-free programming is impossible, since we are *not* machines. A study at Carnegie Mellon University recently found that programmers average 100 to 150 mistakes per 1,000 lines of code.

Simonyi wants to rid the programmer of the burdens of all of the third and a large part of the first and second tasks. He seeks to not only automate the dronelike parts of pro-

Extreme Programming: The Zero G Experience

Zero G is a survivor. The San Francisco company makes installation software—the programs that run when you're putting new software on your PC. Its headquarters are in the once booming south-of-Market area, where it has remained happily profitable even as its former dot-com neighbors have disappeared. But it almost bit the dust along with them, says president and cofounder Eric N. Shapiro—not because of the economy, but because of the slapdash way it wrote software before adopting a methodology known as "extreme programming."

The change came not a moment too soon. Until last year, Zero G—like many software companies—followed a six-month cycle for developing new releases of its products, with marketing handing the engineers a list of features, and the engineers agreeing to transform them into software code by a certain date. According to Shapiro, at the beginning of the cycle, engineers would cherry-pick the features that looked the most fun to program, rather than those most important to the customer. Consequently, in early 2002, as the May ship date for Zero G's release of its InstallAnywhere software grew closer, company programmers found themselves working 15-hour days to complete all the required features, even as the marketing department tried to foist new requests on them. The programmers heroically coded one fix after another, only to find that each fix broke something else. The bug list grew longer every day.



Zero G programmers often work in pairs to get things right.

ANGELA WYANT

The result? "It was the worst product we ever shipped," says Shapiro. The release was not only buggy, it was booby-trapped. Disaffected engineers had revolted, adding features of their own, including a hidden routine—known in the industry as an "Easter egg"—that caused customers' monitors to go black on April Fool's Day. Predictably, the self-sabotage led to a barrage of customer service calls, not to mention lost accounts.

Shapiro recognized that the future of his company depended on its doing better the next time. And with remarkable foresight, he realized the problem lay not in his people, but in the development process itself. Rather than blaming his engineers, he decided to test the extreme-programming methodology, which at its core is about relying on software engineers' instincts about what works and what doesn't, and which had been gaining a rabid following among developers who had tried it and found that it worked.

"I had the idea in mind of taking everything good about software and cranking it all the way to 10," says programming guru Kent Beck, who began developing the concept of extreme programming while consulting for Chrysler in 1996. "All the stuff that programmers are naturally suspicious of, we'd not do at all."

If testing is a good thing to do, for example, then test all the time. If programmers are suspicious of long development cycles, then break the long cycle into chunks that are as short as practically possible—

gramming but also make the programming interface so intuitive that the insurance specialists or accountants or aircraft designers can see their contributions and make improvements by bringing their own expertise to bear, without the programmer as intermediary. Once programmers are freed from the inappropriate tasks that now burden them, they will be able to concentrate on the task for which they *are* uniquely trained: the design of the program itself.

"The real question is, what are we trying to do with this [piece of] software?" Simonyi says. "That's what intentional programming will allow us to concentrate on. When you want to create a wonderful system for health care, you should be concerned with the problems of health care and how to solve them. But the way we write software now, the understanding of those problems is lost, because the programmer needs to be concerned instead with how to sort numbers, or how to store data on a disk."

PROGRAMMING IN PICTURES

When you ask Simonyi to explain just how the dronelike parts of programming might be automated, eliminating bugs caused by human error, he will tell you a story about jet engines.

"Think about the turbine blades," he says. "They have to be perfect. If you were to use the most meticulous craftsman to make them, you still wouldn't get anywhere near the degree of accuracy you need. You need to create a machine to make the blades. Are humans involved in the process? Of course. You need them to build the machine, and to maintain it and adjust it. Can machines fail? You bet! But they fail in a disastrous way, and you can see it right away and can fix it. It's the same thing with code! You don't want humans to touch it. It will have bugs in it! Can humans do something? Yes. They can build the machine."

What, exactly, would a machine for writing software look like? It would itself be software. But its function would not be to solve the end problem—to perform some new home or office task. Rather, it would be a software "generator," causing a particular piece of software to be written. Telling the generator what program to write would be accomplished through an easy-to-understand interface, sometimes referred to as a "modeling language."

The most widely adopted modeling language today is the Unified Modeling Language, which evolved from work Booch and fellow programmers James Rumbaugh and Ivar Jacobsen did at Rational Software—and which is now being developed by the open-source software community under the stewardship of IBM and the other members of an industry consortium called the Object Management Group. The Unified Modeling Language is a system for creating diagrams. It's intended to let managers of large software projects visualize their designs and make sure they meet the clients' requirements before programmers sit down to write code in programming languages such as Java or C++.

Simonyi's vision, and the reason he started his company, is to take the idea of models and go one step further: to link the model and the programming so tightly that they eventually become the same. Programmers and users will be able to switch between many contrasting views of the model they are creating, and revise programs at will simply by tweaking the models *(see "Just-in-Time Programming," p. 41)*. It's something like an architect being able to draw a blueprint that has the magical property of building the structure it depicts—and even, should the blueprint be amended, rebuilding the structure anew.

"It goes all the way back to the notion of 'what you see is what you get,'" says Gregor Kiczales, who left his part-time position at the Palo Alto Research Center last year to cofound Intentional Software with Simonyi but has since returned to his longtime position at the University of British Columbia in Vancouver, where he is a professor of computer science. Kiczales champions a programming technique known as aspect-oriented programming, which allows programmers to edit all instances of related commands quickly, even within a

EXTREME-PROGRAMMING PRECEPTS

Like a 12-step program with its inspirational prayers and mottoes, extreme programming has its own list of commandments for software developers. A selection:

- **Do the simplest thing that could possibly work**. If a program is so complex that it will be hard to modify later, it is just too complex.
- **You're *not* gonna need it**. Save time by implementing new features when you actually need them, not when you foresee that you'll need them someday.
- **Code reviews are good**. Programmers should work in pairs, sharing one screen, so that all code is reviewed as it is written.
- **Interaction between developers and customers is good**. Have a customer on site who can prioritize work for the team and answer questions as they arise.
- **Work at a pace that can be sustained indefinitely**. Work overtime only when it is effective. "Death march" projects do not produce quality software.

say, two or three weeks, each culminating in a modest goal that engineers can commit to, knowing they will meet it. If frequent code reviews are helpful, then review continuously, having programmers work in pairs and check each other's code as they go. If programmers complain that customers keep changing their minds, then plan for customers who change their minds: the shorter cycles allow wholesale revisions every few weeks, when a new cycle begins and new goals are set.

Zero G's results have been dramatic. Shapiro says that the company's latest version of InstallAnywhere—written entirely using the extreme-programming methodology and released last May—packs much greater functionality than the May 2002 version in fewer lines of code, and comes without any Easter eggs. Morale is up, too. People like their jobs again.

"In the traditional way of doing things, developers get a long list of features and a long timeline," says Shapiro. "By the time the software is done, customers have changed their minds. With a two-week development cycle, we're able to respond. We don't have to be geniuses."

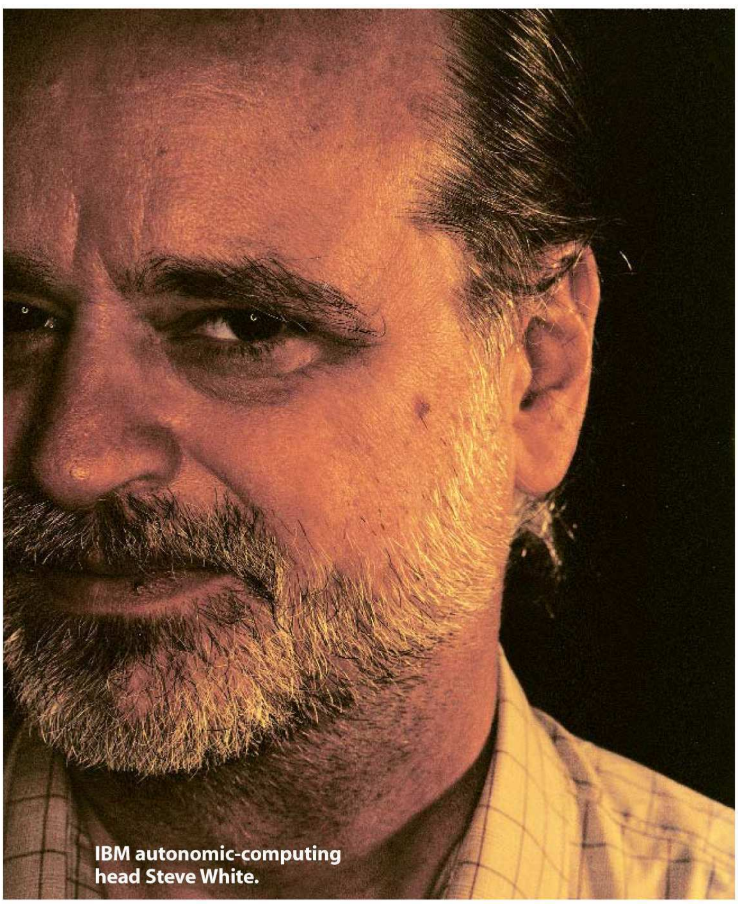
From Artificial Intelligence to Artificial Biology?

The ultimate goal for programming: software that heals itself.

For decades we've thought of computers as centralized intelligences; our model was the human brain. But lately, a growing number of researchers have been talking about a shift in the core metaphor for computing, from the notion of "artificial intelligence" to something that might be called "artificial biology." Forget about the dream of creating bug-free software. Just as bugs regularly affect any biological system—I have a cold as I write this—they should also be expected in software. So software needs to be designed to survive the bugs. It should have the biological properties of redundancy and regeneration: parts should be able to "die off" without affecting the whole.

This shift is not only transforming the research of leading academic groups at places like Stanford University, the University of California, Berkeley, and the University of Virginia but also influencing the development of commercial products: IBM and Oracle have both introduced products such as Web servers and database programs that they describe as "self-healing," a term typically applied to biological organisms. In 2001 Paul Horn, head of IBM Research, wrote a widely read white paper describing the notion of "autonomic computing" and calling on the computing research community to begin thinking of ways to design systems that could anticipate problems and heal themselves.

The point of autonomic computing—and by extension, of self-healing software—is to give networks and computer systems the ability to regulate and repair things that now require human thought and intervention. For example, servers need to be rebooted now and then to keep them working. That can happen because of "memory leaks" created by software bugs, explains Steve White, who heads up IBM's autonomic-computing research from the T. J. Watson Research Center in Hawthorne, NY. "A program will take up more and more memory to run," he says, "so eventually it breaks. Start over, and it will work." At the moment, users need to recognize problems themselves and physically reboot their systems. But with autonomic computing, "You can make it possible to reboot a system easily and automatically," says White.



IBM autonomic-computing head Steve White.

In the future, the biological metaphor may even affect the way we program to begin with. Software could eventually "heal" some of its own bugs, supplementing catch-all fixes—like automatic rebooting—that don't get at the core problem. But that will require an entirely new approach to programming.

"We need to move towards a programming philosophy where we look at the global system and understand what properties it needs to have, rather than thinking about programming as a sequence of instructions," says David Evans, who is pursuing biologically inspired programming methods as a computer science professor at the University of Virginia. "It's really a different way of approaching problems."

Evans notes that software today is written linearly, with each step depending on the previous one, more or less guaranteeing that bugs will wreak havoc: in biological terms, organisms with no redundancy don't survive long if one means of accomplishing a task fails. More robust software would include many independent components so that it will continue to work even if several of its components fail.

Even today, programs such as Microsoft's Windows XP operating system are beginning to exhibit the biologically inspired ability to detect problems and to fix them, albeit in a simple way, by storing models of their original configurations. The programs can then be restored to their original states if bugs corrupt them later. And good compilers—the programs that translate human-readable languages into machine-readable code—will identify potential errors and return error messages along with suggested fixes. But these methods still require programmers to predict problems and write code that guards against them to begin with—and we predict flaws in our software about as well as Dr. Frankenstein predicted the flaws of his artificial man.

How close have we come to writing software that, like the human body, can identify and correct problems we haven't thought of?

"We haven't developed anything that is very persuasive yet for healing unanticipated conditions," says Tom DeMarco, longtime software pundit and principal with the Atlantic Systems Guild, an international software training and consulting group. "You have to remember that software doesn't break. It is flawed to begin with. So for software to self-heal, you have to find a way to have the program create things that were not there when the program was written.

"We'll get there someday."

WALTER SMITH

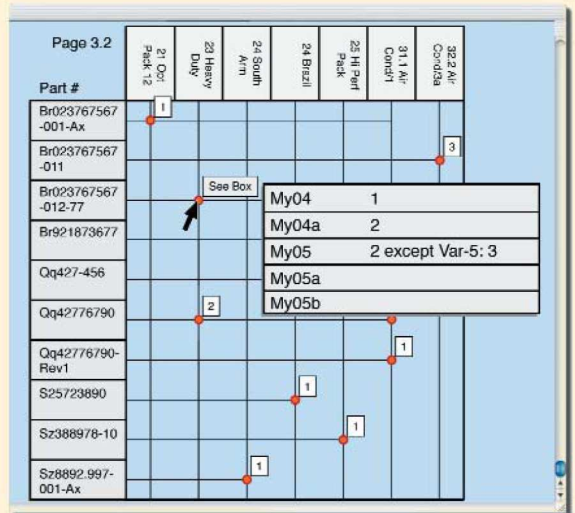
very complicated program—just as a word-processing program can locate and replace every instance of a misspelled word. It's a technique that will support the underlying architecture of intentional programming. "The idea of intentional programming is, what if we did that not just with word processing, but with programs?" says Kiczales, who remains a consultant at Intentional Software.

Simonyi describes the new model for generating programs as looking very much like a PowerPoint palette, which anyone can use to create presentation slides by pasting text, charts, or images into different sections of an intuitive virtual workspace. But Intentional Software also believes that different types of problems may call for different interfaces, to meet the needs of different clients. Scientists working with computer simulations, for example, might want to use a generator programmed to mechanically translate mathematical descriptions into the corresponding code.

The kind of software Simonyi envisions will not only relieve tomorrow's programmers from the need to behave like machines; it will also enable experts in a given field—insurance, accounting, health care—to make their own changes to their software, easily and without the constant aid of a programmer. Suppose you are a corporate accountant using custom financial software, and a new tax law is passed, Simonyi posits. "You can edit the description of what you want to do on your own, and now you run the generator again. You don't involve programmers again. The generator runs at computer speed, about a billion times faster than human, and a billion times more precise, and you get your change."

Just-in-Time Programming

In this hypothetical intentional software program from a "just in time" auto parts ordering system, option packages run across the top, parts numbers along the left. Any changes a factory manager adds—say, information for a new model year (pop-up box)—would be automatically reflected in the software code.



JOHN MACNEILL; SOURCE: CHARLES SIMONYI

THE REBIRTH OF SOFTWARE

When these tools are developed—and even the ever optimistic Simonyi says it will take at least two years for his company to put a product on the market—the simplicity they bring to programming will not be their only benefit. They will also allow programmers to build software of a complexity we can't approach using today's methods.

But Simonyi's colleagues and competitors have their own, often very different ideas about how to use modeling to save software from the burden of its increasing complexity. There's Booch, for example, who is hoping to enrich the Uniform Modeling Language by building in a broader version of Kiczales's "aspects," so that, for example, functions like security and authentication would automatically weave themselves through entire software systems. He's also involved, he says, in "finding ways to represent larger and larger abstractions"—that is, going beyond models of individual programs to models of the overall architecture of huge software projects.

"Writing software is fundamentally a very complex problem, and it's getting worse," says Booch. "We're routinely writing applications now that have several million lines of code. To do that you have to build in an illusion of simplicity. Models let us do that."

James Gosling, a research fellow at Sun Labs and the inventor of Java, is another recent convert to modeling. But again, the emphasis of his research is different. Recognizing that the software industry constantly reuses old programs, Gosling proposes finding a way to plug existing code into a modeling tool that will represent it graphically, rather than requiring programmers to pore over millions of lines of text. Theoretically, we could feed all our old, bug-riddled programs into such a tool, examine their underlying design, and identify their logical flaws.

"Like most programmers, I'm a big fan of starting over," says Gosling. "But people almost never have that luxury. We're building a tool that will read a very large system, say, two or three million lines, and will make it easier to understand."

Code-named Jackpot, the project is still small, well outside Sun's product development process. But it's something that both Booch and Simonyi are enthusiastic about, as it is one more indication that modeling is becoming a force that will move the industry.

When will we be able to generate complex code from models alone? While Intentional Software has not yet marketed products, it plans to make concrete announcements in 2004. IBM's purchase of Rational and commitment to the Unified Modeling Language, along with Sun's interest in the concept, indicate that these ideas are achieving critical mass.

The challenges these visionaries are grappling with are huge. Yet their success also feels inevitable, because what they are proposing makes far more sense than believing that we can make a perfect thing out of millions of handmade pieces—a flaw in any one of which can break the whole. Which is exactly what we're trying to do with software today.

"Software is so flexible, and the promise is so great, and the conventional improvements we're used to today are nothing compared with what we will be able to do tomorrow," says Simonyi. "Look what the hardware people have managed to do with Moore's Law. Now it's going to be software's turn." TR

Claire Tristram is a *Technology Review* contributing writer based in San Jose, CA.

trash your desktop

IF SOFTWARE PIONEER MITCH KAPOR GETS HIS WAY AGAIN, ALL THE ELECTRONIC INFORMATION YOU NEED—E-MAIL, ADDRESSES, APPOINTMENTS, DOCUMENTS, AND MORE—WILL ALWAYS BE AT YOUR FINGERTIPS. WELCOME TO CHANDLER, A BOLD ATTEMPT TO REINVENT THE WAY WE USE COMPUTERS TO MANAGE IDEAS.

by michael fitzgerald | photographs by angela wyant

Kapor's calling: Lotus founder Mitch Kapor sees Chandler as a return to his first love—software.

"Thwump" sounds happen in boxing matches, not offices.

So when a loud thwump bounces off the exposed-wood ceiling in an office in San Francisco's once trendy south-of-Market district, every head turns. Programmer Jed Burgess is flat on his back next to a blue fitness ball. Burgess gets up, pulls his socks off for traction, and manages to balance atop the ball. Applause breaks out. Then the office returns to quiet discussions of software architecture punctuated by the clicking of keyboards. Welcome to Mitch Kapor's Open Source Applications Foundation.

Kapor himself, famous as the founder of Lotus Development and one of the software industry's chief malcontents, is away from the commotion. But if his foundation succeeds, it'll make a thwump the entire software business will hear. The organization's 13 programmers are hard at work on a piece of software that could change the way we manage our digital lives, curing the headaches of having to juggle the dozens of types of information stored on personal computers by a variety of applications—and, Kapor hopes, making computer users happier and more productive in the process.

Code-named Chandler, after the mystery writer (because, Kapor says, what they're creating was something of a mystery even to them when the venture launched two years ago), the software promises to put all related e-mail messages, spreadsheets, appointment records, addresses, blog entries, word-processing documents, digital photos, and what-have-you in one place at one time: no more opening program after program looking for the items related to a specific topic. It takes the core functions of Microsoft Outlook, the Palm Desktop, and other personal information management programs and integrates them with the rest of your PC and the Internet. All the information you need to complete a given task or project is grouped on-screen, organized around the one function—e-mail—Kapor sees as the central conduit of our electronic lives.

Because Chandler presents information in its logical context—displaying all related items together—and not in the separate folders and application windows of the traditional desktop computer system, you can think of it as a new way into your computer. "It may be hubristic," says Kapor, "but we're trying to push the edge of the envelope in terms of innovation, and trying to pioneer a new type of interface"—one that he thinks is sorely needed. "Software is too difficult, too limiting, and pretty severely so, and it's a raw deal. The average user really gets screwed."

Ending this "screwage"—a term that pops up frequently in Kapor's Web log—is important enough to the software tycoon that he's funding the foundation with $5 million of his own money. And this summer, Kapor gave *Technology Review* the first in-depth look at Chandler and the organization building it. Word about Chandler has gotten out through conference presentations, Kapor's blog, and the foundation's Web site, creating a buzz in programming circles. It's a "very interesting project to watch," says Chad Robinson, an analyst with the Robert Frances Group, a Westport, CT-based computer consultancy. "They are focusing on completely redesigning how you interact with" the data that flows through your computer every day. Robinson calls this strategy "wildly ambitious and a total crapshoot."

Indeed, achieving success will require a shift in the way both programmers and users think about how computer data is presented and organized. Not only that, Chandler is an open-source project—meaning that unlike commercial software, it will depend partly on the work of volunteer programmers, and its resulting code will be free to all. It's audacious to try to build a user-friendly program without the structure imposed by market requirements and shipping deadlines, and whether the project can succeed by Kapor's intended December 2004 release date is, so to speak, an open question.

In its favor, the Chandler team has some stellar volunteers, including Andy Hertzfeld, a programming demigod who built much of the original Macintosh operating system, and Lou Montulli, one of the founding engineers at Netscape, along with a core, paid staff of programmers like balance-ball Burgess.

At stake is a new, more intuitive way of handling information that could be as revolutionary as the replacement of the text-based, command-line interfaces of the earliest personal computers with graphical computer desktops. That's the vision that pushes Kapor—though he would prefer to be designing software—to spend much of his time imposing structure on the project. "I'm the benevolent dictator," he says.

Chandler & Outlook

Microsoft Outlook and Chandler will have common elements, such as a calendar, e-mail reader, and contacts list, but Chandler hopes to add a number of novel features as well:

- An adaptive user interface that displays all the information relevant to what you are working on, no matter what form it is in—e-mail, word-processing document, digital photo, or Web page
- The ability to run on Windows, Macintosh, and Linux systems (Outlook does not work on Linux, and not all features are available for Macs)
- Built-in instant messaging
- The ability to swap out the calendar, the e-mail reader, and other software components if someone writes programs you like better
- Calendar and contact sharing that doesn't require a central server (and someone to maintain it)

A NEW AGENDA

Kapor hopes Chandler will draw droves of converts but says he knows how fickle the software business can be. The seminal Lotus 1-2-3 spreadsheet was the must-have application that did more than any other to launch the personal-computer revolution. But Kapor, who founded Lotus in 1982, left the company five years later to lead On Technology, which had less success. He quit the software world altogether in 1990, when he cofounded the Electronic Frontier Foundation, a digital-civil-liberties group that filed, and won, some of the earliest cases involving privacy

Software revolutionaries: Chandler has attracted some of the best and most irreverent programmers.

protection and free speech online. After that, Kapor became a philanthropist and investor, hitting it big with founding investments in Real Networks, the Seattle-based streaming-media giant, and UUNET (now part of MCI), which runs the largest privately owned chunk of the Internet's backbone network.

Now he's back to his first love, software design. He thinks most of the "productivity" programs available to workers and consumers today are too complicated and inflexible. Case in point: Kapor and his wife Freada Kapor Klein, who leads a small sexual-harassment consulting firm, wanted to use the calendar-sharing feature of Outlook to coordinate their schedules and those of their assistants. But to do so they had to install and administer Microsoft Exchange, a heavy-duty server program for corporate messaging and collaboration Kapor calls expensive and hard to maintain. "It's total overkill and it's horrible," he says.

That experience was on Kapor's mind as he considered reviving the ideas behind Agenda, a database and information organizer that was his Lotus swan song. Agenda automatically stored free-form database entries—such as "Call Alice on Friday about the Australia trip"—under multiple categories, such as phone calls, Alice, Australia, and Friday. It then recalled the entries at the appropriate times—for example, when the user reviewed Friday's to-do list. Even though Agenda ran on Microsoft's original DOS operating system, requiring users to learn many typed commands, devotees raved about the program's ability to sort related data from disparate sources. But the program never sold well, and Lotus abandoned it after Kapor left.

Kapor thinks Agenda was merely ahead of its time. And because so many of the ideas that keep our lives and businesses humming are now shared over the Internet, he believes that any program that revives some of the principles behind Agenda should be, first and foremost, built around the Internet's killer app: e-mail. Despite the Internet revolution and the tremendous amount of money and energy invested in creating software for it, the main interface to your computer—the desktop—looks much as it did the first time you used a computer that featured graphical icons, even if it was a Macintosh in 1984. But with Chandler, Kapor envisions e-mail as the main interface with computers, with entities like calendars, contact managers, instant messaging services, and file folders grouped around *it*.

"People spend enormous amounts of time in their e-mail; we're totally e-mail-centric. It's the hot ticket in productivity applications," Kapor says.

SECRET AGENT MAN

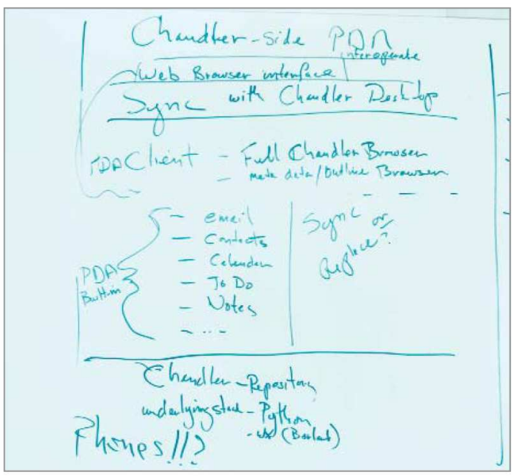
Chandler puts the user's convenience above all else—which means the way e-mail and other entities are grouped is changeable, depending on the tasks at hand and how users want their information arranged. The foundation's programmers are calling the groups of files "contexts," since the point is to let users easily access related items, and to control what types of items appear.

The "to-do" screen, for example, could be a context, with e-mail mixed in with related task items. So if you're planning a party, Chandler might put a calendar with key dates on it (when to pick up a cake, say), the invitation form, RSVPs, a task list, and even a budget on-screen at once. When a guest's e-mail request for veggie hors d'oeuvres arrives, arranging for them would auto-

matically be added to your to-do list. Contexts will mean Chandler can reorganize the screen every time the user shifts between projects, as if she were replacing her desk with a new one. That's a far cry from today's software, which forces people to dig through applications and file folders to find things, and to print them out if they want to see everything in one place. And while Chandler will offer preset contexts, Kapor expects other open-source programmers to build them, too. If someone develops a better way to run spreadsheet analyses, a user can simply pull out existing contexts and replace them. (Try that with Outlook.)

Driving some of Chandler's flexibility will be a technology with a checkered past: software agents. These are small pieces of code typically designed to perform individual tasks, such as beeping when an e-mail message arrives. Attempts to build more sophisticated agents, such as Microsoft's much-loathed "Clippy," an animated paper clip that purports to help people use Microsoft Office programs, have faltered. That's where Chandler volunteer Andy Hertzfeld comes in. The exuberant, boisterous programmer, whose Mac OS remains perhaps the most user-friendly program ever, thinks agents done well could reshape how people use software. "On the network, there's a whole world that's constantly churning out there," he says. "So can we allow end users to express their desires automatically and then track them?" For instance, Hertzfeld asks, why shouldn't your computer have an agent that will perform mundane tasks such as making hotel reservations when it finds a room for the right price, or update your address when it sees that a friend's contact list is out of date?

Hertzfeld can't resist plays on words—he's working on "postal agents" for e-mail, "travel agents" for booking trips, and "secret agents" to handle software encryption. But his purpose is not to be whimsical. "Mitch is afraid I'll make it too cutesy," he says. "I have to make things Mitch-friendly."



Beyond blue sky: A hand-scrawled list shows features that will let Chandler interact with handheld devices.

FROM BLUE SKY TO NUTS AND BOLTS

As Chandler's lead designer, Kapor has fun dreaming up new things. But he's also the boss. "You can't coordinate a project of this scope in an ad hoc structure," he says. In one of the programming team's regular Thursday morning meetings, Kapor lays down the law. "We should aspire to a rare and unprecedented level of honesty" about schedule slips and bugs in code, he tells the team. Kapor's voice is slightly hoarse, a vestige of his pre-software days as a DJ, and he has a balky back, so he's often more comfortable in meetings when he stands. He commiserates with the staff about the difficulty of meeting targets, saying "things never take shorter, they always take longer.…We're not going to change human nature here. But let's have a reality-based schedule, if we can bring ourselves to do it. We're not VC-backed, so we have more of an opportunity to do things differently."

The chance to work with Kapor on a groundbreaking product has attracted exceptional software people. Besides Montulli, a number of other former Netscapers are involved. John Anderson, who has to figure out how to build what Kapor dreams up, is one of Silicon Valley's best contract programmers. E-mail architect Kaitlin Duck Sherwood has spent most of her life around computer messaging: her parents worked on PLATO, a seminal 1970s communications project at the University of Illinois. Hertzfeld seems to speak for them all when he says, "The purpose of coming in to work every day is to improve life for the user."

But that won't be easy. Though Kapor has put serious resources behind the foundation, Chandler is by no means a sure bet. The project has moved slowly since its kickoff in the summer of 2001, with more vision than code to its credit so far. Critics say Kapor is better at concepts than execution, noting the failure of several of his products after 1-2-3, including Agenda. And Kapor's attempt to reorganize functions like e-mail, calendaring, and contact management has some labeling Chandler an "Outlook killer" and questioning the wisdom of taking on Microsoft. Kapor, however, says it would be "psychotically suicidal" to challenge Microsoft commercially, and he thinks it's far fetched to talk about dislodging Outlook from its market dominance anytime soon. Still, since he does expect Chandler to have mass appeal, he says if that forces Microsoft to rethink its approach to applications, great.

Kapor says the skeptics are also missing the point when assessing the group's progress. After all, it was only in August, once the idea of contexts coalesced, that Kapor declared the end of the "blue sky" phase of the project, directing programmers away from developing models and demos to actually writing code for the program's major pieces. Kapor now believes that late 2004 is a realistic ship date for the first full version of Chandler.

And while some doubt, too, that open-source efforts can produce programs that rival commercial software, the spread of products like Linux suggests otherwise. Indeed, Douglass Wilson, chief technology officer for Lotus (now a division of IBM), says that open-source methods can build very high-quality software "by virtue of having lots of eyes." He says the key is getting the right eyes. "What makes open source go is the community. If a technology spawns a community of interest…then you have both a very powerful creative force and a market force."

It's too early to say whether Chandler will develop such a community. Besides the technical challenges and the user issues, it's hard to picture exactly what Chandler will look like, and until its basic framework exists, developers outside the foundation's San Francisco office can't write code for it.

So will Chandler succeed? Kapor pauses. "Uh, uhhh, yeah.…" And suddenly Kapor the open-source advocate morphs into Kapor the CEO, and asserts, "It's like any other startup. When you're doing something new and different, there are always risks. But I'm increasingly confident that it's going to work." He chuckles. "But maybe you caught me on a good day." TR

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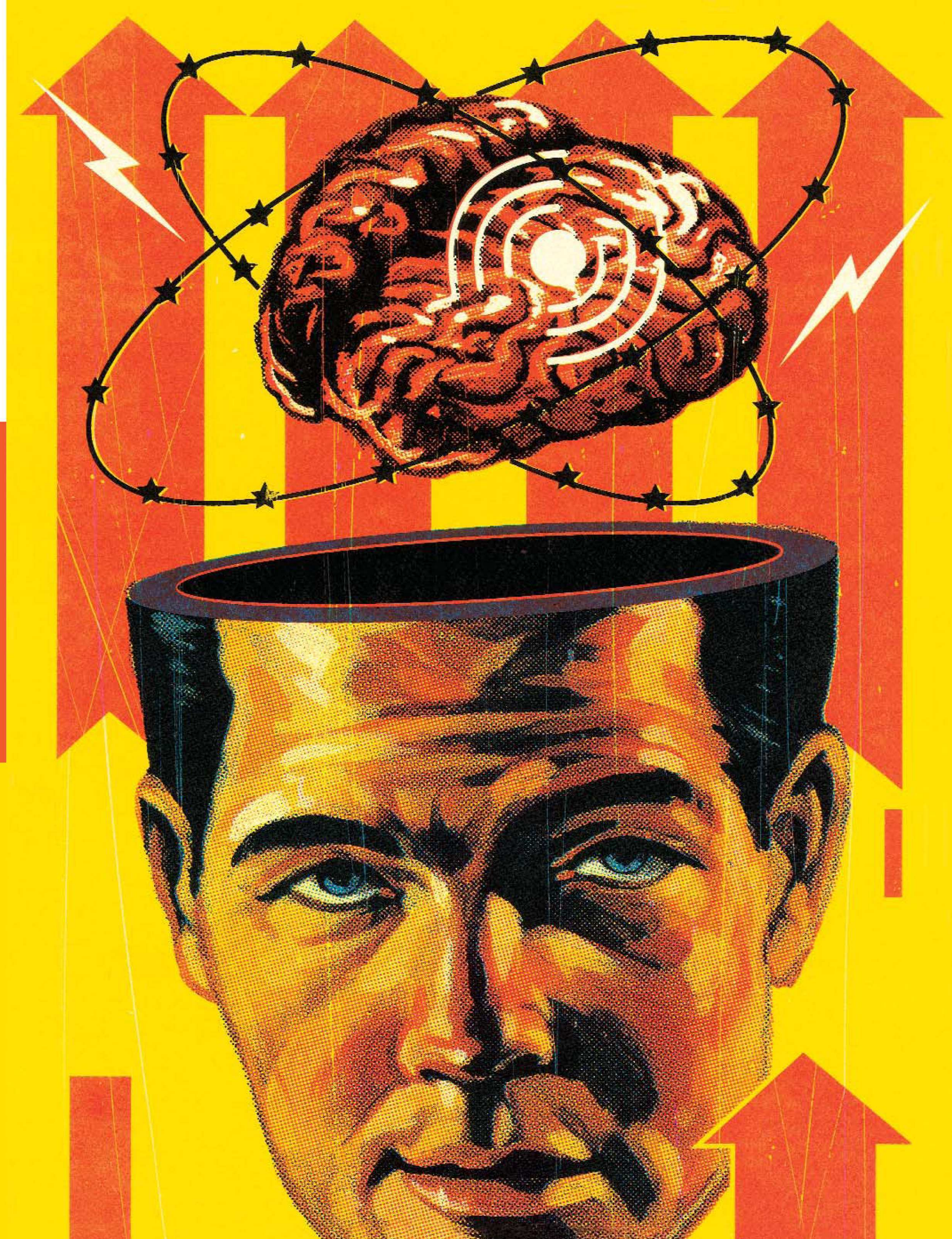
stopping PAIN

ADVANCES IN NEUROSCIENCE ARE LEADING TO A NEW ERA IN MEDICINES FOR SEVERE PAIN. BY SHORT-CIRCUITING PAIN SIGNALS, THESE DRUGS ARE POISED TO CURB THE SILENT EPIDEMIC THAT AFFECTS TENS OF MILLIONS.

by ken garber illustration by tavis coburn



On April 29, 1997, the supermarket tabloid the *National Examiner* ran this headline on its cover: "Miracle Pain Cure: Deadly Snail Venom." The garbled story within contained a kernel of truth. Doctors in fact were injecting a drug derived from the venom of a marine snail into patients suffering from the worst kinds of pain imaginable.

One of the researchers responsible for this unlikely drug, neuroscientist George Miljanich, sits beneath a framed copy of the tabloid cover, which shares wall space above his South San Francisco, CA, desk with more staid covers from the journals *Molecular and Cellular Neuroscience* and the *Journal of Neurocytology*, among others. Miljanich works for Dublin, Ireland-based Elan Pharmaceuticals, and his snail-derived drug is called ziconotide.

For the last 50 million years, predatory snails in the Pacific Ocean have been stabbing passing fish and killing them with their venom. In tiny amounts, though, one component of the venom actually blocks the pain in desperately sick and injured people—at least among the nearly 2,000 who have tried it to date. "Ziconotide is about a thousand times more potent than morphine," Miljanich says. "Upwards of a third of these patients experience significant improvement in their quality of life."

Ziconotide is not yet approved by the U.S. Food and Drug Administration, and because it can cause severe side effects, its future remains uncertain. But its ultimate fate in the marketplace is, in a way, beside the point. Because of its effectiveness in halting pain, ziconotide has spawned a new generation of drugs deliberately designed to block the electrical impulses that generate pain signals, without affecting other systems in the human body.

Making headlines: Neuroscientist George Miljanich researches new pain drugs.

These efforts represent an entirely new way to treat pain, one with such commercial promise that at least a dozen companies—from small biotech companies to pharmaceutical powerhouses such as GlaxoSmithKline and Merck—are investing billions of dollars in an effort to improve on nature by creating synthetic molecules more potent and safer than ziconotide. Human trials of some of the drugs could begin within the year. "The idea here would be a drug that only takes out the pain," says neuroscientist Allan Basbaum of the University of California, San Francisco. "And that's on the horizon."

The need is pressing. According to the American Pain Foundation, more than 50 million Americans suffer persistent pain. Morphine, first chemically isolated from the poppy plant 200 years ago, remains the drug of choice for severe pain. Despite its many side effects, including drowsiness, interference with breathing, constipation, and the potential for addiction, "no one has bettered it," says University of Michigan pharmacologist John Traynor.

Many "new" painkillers are in fact anything but, and they have problems similar to morphine's. OxyContin, for instance, is actually a morphine derivative that has been in use since 1917. The difficulty with all of these older drugs is that they act throughout the nervous system, not just on pain-sensing nerves—hence their side effects.

A few more-selective new drugs do exist, including the cox-2 inhibitors used to treat arthritis pain (Merck's Vioxx or Pfizer's Celebrex, for example), but for really severe pain, they might as well be

EMILY NATHAN

sugar pills. People with postsurgical pain, intense cancer pain, traumatic injuries, and severe chronic back pain must often still resort to morphine and its narcotic cousins for relief. And sometimes, even morphine is not enough.

Seven years ago, Vicki Wiltshire was rear-ended while driving to a physical-therapy appointment; the collision aggravated a back injury she had suffered earlier and sent her into a spiral of pain and despair. Four surgeries later, the former realtor has screws and rods in her spine, three fused discs, and masses of scar tissue. She cannot bend or twist without excruciating pain.

Suicide, at times, has crossed Wiltshire's mind. "We don't have guns in the house," she says. "You cannot live in that kind of pain day in and day out." Such chronic pain is not a dull throbbing. "Your body is screaming constantly," says Elaine Casanova, a former secretary who wrecked her back in a small-plane crash. "Think about having a toothache for 10 years."

MORE THAN 50 MILLION AMERICANS SUFFER PERSISTENT, SEVERE PAIN.

Both Wiltshire and Casanova have taken morphine and other narcotics for long periods. Narcotics dampen but do not douse the pain, and Casanova became addicted, adding another layer of misery to her life. Both women are now on ziconotide, which they say has provided a kind of breathing space in their suffocating world of pain.

It is just those kinds of anecdotes, backed by growing insights into the neuroscience behind pain, that are finally offering realistic hope for new drugs that attack pain without producing debilitating side effects.

beyond morphine

The new pain drugs target ion channels, porelike molecules on the surfaces of cells that open and close like tiny, gated tunnels. Ion channels are present in all cells, perhaps because the earliest living organisms evolved in salt water, with its high concentrations of sodium and chloride ions. Indeed, ion channels that control cells' intake of sodium and calcium regulate everything from the secretion of hormones to the beating of the heart.

In nerve cells, when ions pour in through the opened channels, they generate an electrical spike. In pain-sensing nerve fibers, this spike causes pain. Acute pain has benefits: it alerts the body to injury and can prevent additional damage. But most chronic pain serves no purpose. So if one shuts the gate, the theory goes, chronic pain disappears. Now, with the identification of dozens of ion channels, new knowledge of their biology, and a rapidly growing arsenal of chemical compounds to block them, the theory appears to be on the verge of leading to new drugs.

The key is several recently discovered ion channels that seem to be found exclusively on the specialized nerve fibers that sense pain. "If you can develop drugs to target them…," Basbaum says. He doesn't need to finish his thought. Analgesia without side effects: the ultimate answer for pain.

Drugmakers have embraced the idea, and one of their most promising targets is the capsaicin receptor. Capsaicin, the chemical that makes chili peppers hot, can cause intense pain, as anyone who's accidentally touched an eye after handling hot

Excruciating pain: Vicki Wiltshire's chronic pain has been eased by an experimental drug.

DAVE LAURIDSEN

peppers knows. (Paradoxically, capsaicin applied over several hours can actually relieve pain—for reasons that are hotly debated—and capsaicin creams are sold over the counter to treat conditions like arthritis.)

In 1997, University of California, San Francisco, neurobiologist David Julius isolated the capsaicin receptor. It turned out to be an ion channel that opens not only when capsaicin binds to it but also in response to heat and acidity. When the channel opens, calcium ions flow in, causing the nerve to fire and sending a pain impulse toward the spinal cord and brain. Since the capsaicin receptor is only found on pain fibers (and, possibly, in the brain), and because it has the remarkable ability to detect different types of painful stimuli, blocking it could work beautifully for pain relief.

The capsaicin receptor has drawn the interest of Novartis, Pfizer, GlaxoSmithKline, Merck—"Every major drug company,

"We don't have guns in the house. You cannot live in that kind of pain day in and day out." —VICKI WILTSHIRE

as far as I can tell," says Julius. "Probably the biggest market is osteoarthritis," says Jim Krause, senior vice president of biology for Neurogen, a Branford, CT, biotech company working on capsaicin receptor blockers. Cancer pain is another possibility, since bone metastases result in acid conditions that might trigger the receptor or similar ion channels.

And neuropathic pain—that is, pain caused by nerve injury—is yet another tantalizing target. Diabetes, cancer, AIDS, kidney disease, chronic infections, and even some prescription drugs cause neuropathic pain, which is often untreatable. Though it appears that no company is currently testing a drug based on a capsaicin receptor blocker in humans, Neurogen may be the closest and hopes to start testing its compound in humans within a year.

changing channels

Blocking the capsaicin receptor prevents pain neurons from firing in the first place, but ion channels that help transmit pain signals could also prove good drug targets. Once a pain receptor like the capsaicin receptor is activated, the initial electrical spike causes sodium ion channels to open in sequence down the length of the nerve, conveying the electrical impulse all the way to the nerve's end. But this sequential opening happens throughout the nervous system, not just in nerves that signal pain. Local anesthetics, in fact, block sodium ion channels, but do so indiscriminately, thus eliminating all nerve activity. Given orally or injected into the bloodstream, local anesthetics would cause paralysis and death.

A dozen sodium ion channels have been identified. But a second sea creature clued researchers into a sodium ion channel found only on pain-sensing nerves. Like the marine snail, the deadly Puffer fish, or blowfish, uses a toxin to kill its prey; this toxin works by blocking sodium channels—with the exception of the channel unique to pain fibers. In 1996 John Wood of University College London and John Hunter at Roche Bioscience simultaneously isolated that channel by relying on its unique resistance to the blowfish toxin.

Target just this sodium channel, researchers assume, and you take out only pain, leaving other nerves free to fire away, happily transmitting impulses all the way to the brain. "It looks like you will get good analgesia in the absence of side effects," says Phil Birch, chief scientific officer of Ionix Pharmaceuticals in Cambridge, England. Ionix, cofounded by Wood, has found several drug candidates that block the sodium channel and hopes to try one in humans by 2005. "Because the target is expressed

The new pain drugs aren't a sure thing: many ion channels look virtually identical, so it's hard to target just one.

only in pain-sensing nerves, [we] can develop a selective blocker," Birch says. "We think it'll have a fantastic profile."

Merck, GlaxoSmithKline, and Elan are also targeting this ion channel. "It's localized perfectly for where you want to block the pain signals," says Elan's Miljanich. Compounds that inhibit it could treat acute and inflammatory pain, such as that caused by arthritis. But even more alluring is neuropathic pain. Nerves damaged by disease seem to have more of these channels, exacerbating the uncontrolled nerve firing of neuropathic pain—pain disconnected from any external injury. Even the best available drug only helps about 30 percent of patients with neuropathic pain. Selective sodium channel blockers could be the first effective drugs deliberately designed to treat their condition.

No one is yet sure they'll work. "In theory, it's a wonderful idea," says Wendye Robbins, a Stanford University pain specialist. "In practice [it's] more complicated." Other sodium channels look virtually identical, so it's hard to target just one. For example, a similar sodium ion channel regulates electrical impulses in the heart, and shutting down sodium channels in the brain would cause stupor. Ionix says its molecules do not block these channels, but the ultimate test will be in humans.

killing the messenger

Other basic questions about the effectiveness of blocking specific ion channels remain unanswered. For one thing, no one is certain that blocking one type of ion channel will be enough; other kinds of channels—there are dozens—might open and cause a spike anyway. "The real question is, will one drug do it?" says Basbaum. He thinks that ion channel blockers may work well for specific kinds of pain, but that no single drug will work for everything. "Is there a magic bullet?" he asks. "The answer is, it may very well be that [drug] cocktails are the way to go."

Still, ziconotide holds out the tantalizing possibility that a single drug might be enough. Nerve impulses traverse the body through a vast system of neurons laid out end to end, not quite touching. The gaps between neurons are called synapses, and certain calcium ion channels are essential to conveying impulses across the gaps. While capsaicin and sodium channel blockers prevent pain-sensing neurons from firing, ziconotide keeps the impulse from crossing the synapse by blocking these calcium channels. So it doesn't matter if the other channels are stuck wide open, causing the first nerve in a pathway to fire violently and endlessly. If the impulse can't cross the synapse, no pain is felt. The first neuron "is firing as fast as it can, but it's not telling the next neuron that anything's going on," explains Bruce Morimoto, director of drug development for NeuroMed, a Vancouver, British Columbia, biotech company.

Ziconotide is too toxic and too hard to deliver ever to be widely used; its side effects include confusion, memory loss, dizziness, and tremors. It fogs the brain the same way it stops pain, by preventing neurons from communicating. But NeuroMed and Ionix are developing next-generation versions of ziconotide. These drugs can be taken as pills and—their developers hope—will avoid ziconotide's worst side effects. The key is to target only nerves that are sending pain impulses. "Under pain conditions, those neurons are firing at a very rapid rate compared to 'normal' neurons," explains Morimoto. "If our compounds are blocking the channel with this very rapid, high-frequency stimulation, [then] we are more likely to hit only the channels involved in pain transmission, and not other ones in the body."

Scientists at NeuroMed identified such compounds by applying tiny electrical shocks to nerve cells. They used minuscule glass electrodes clamped onto single neurons to measure the current generated by the opening of individual ion channels as the neurons fired. The company's compounds were tested, one by one, for their effects on these individual channels. Only those compounds that closed the channels while the nerve fired vigorously became drug candidates.

NeuroMed hopes its lead drug candidate will enter human trials later this year. Ionix anticipates starting tests of its drug candidate by the end of 2004. Only then will we

TARGET: ION CHANNELS

COMPANY	TARGET	STATUS
Elan Pharmaceuticals (Dublin, Ireland)	Select calcium channels	In human trials
GlaxoSmithKline (Brentford, England)	Capsaicin receptors	Preclinical development
	Select sodium channels	In human trials
Ionix Pharmaceuticals (Cambridge, England)	Select calcium channels	Human trials scheduled for 2004
	Select sodium channels	Human trials scheduled for 2005
Merck (Whitehouse Station, NJ)	Capsaicin receptors and select sodium channels	Basic research
Neurogen (Branford, CT)	Capsaicin receptors	Human trials scheduled for 2004
NeuroMed (Vancouver, British Columbia)	Select calcium channels	Human trials scheduled for 2003
Novartis (Basel, Switzerland)	Capsaicin receptors	Preclinical development

begin to know if ziconotide's spectacular but erratic analgesia can be bettered.

a bell in your brain

There is one more cautionary footnote to the tale of the new pain drugs. All the approaches, and the billions of dollars the drug industry has invested in them, teeter on an untested assumption: that blocking nerve impulses in the body's periphery, before the signals reach the spinal cord, is the best way to block pain. This seems self-evident but in fact may be wrong.

> **EVEN THE BEST DRUG NOW HELPS ONLY 30 PERCENT OF PATIENTS WITH NEUROPATHIC PAIN.**

In the 17th century, Descartes postulated that injury generates pain by sending a message via nerves to the brain, as if pulling at the end of a rope to ring a bell. You bash your shin, the rope rings the bell in your brain, and you feel pain. It follows that cutting the rope—blocking the peripheral nerves—should prevent the pain from ever reaching the brain.

But it's not that simple. It's now clear that the sensation of pain doesn't match up consistently with stimulation of pain-sensing nerves. The same injury can produce intense pain in some people and nothing in others, depending on the person's immediate circumstances, past experiences, and state of mind. Soldiers, for instance, may not realize they have been shot until a battle is over. On the other hand, many amputees suffer "phantom limb" pain, in which, say, a missing hand and fingers are felt in every detail.

"There is no such thing as a painful sensation; there are only sensations that get interpreted as pain," says Tito Serafini, a neuroscientist at the South San Francisco biotech company Renovis. The brain's role is central. "Looking at the periphery, simply because we can do it, is going off in the wrong direction," argues John Loeser, a neurosurgeon at the University of Washington. "The processing of information in the brain is probably far more important than what happens in the periphery."

In fact, neuroscientists now know that pain messages do not flow unchecked from the body to the brain. Instead, "gates" in the spinal cord alter the level and intensity of nerve impulses. And impulses descending from the brain can open and close these pain gates.

"Pain is in the brain," Basbaum concedes. Unfortunately, he says, we have no idea how to find a drug that will attack pain via the brain, still the most mysterious organ. "We know the brain is an essential part of the pain experience," he says, "but we just don't know anything about circuitry or the chemistry."

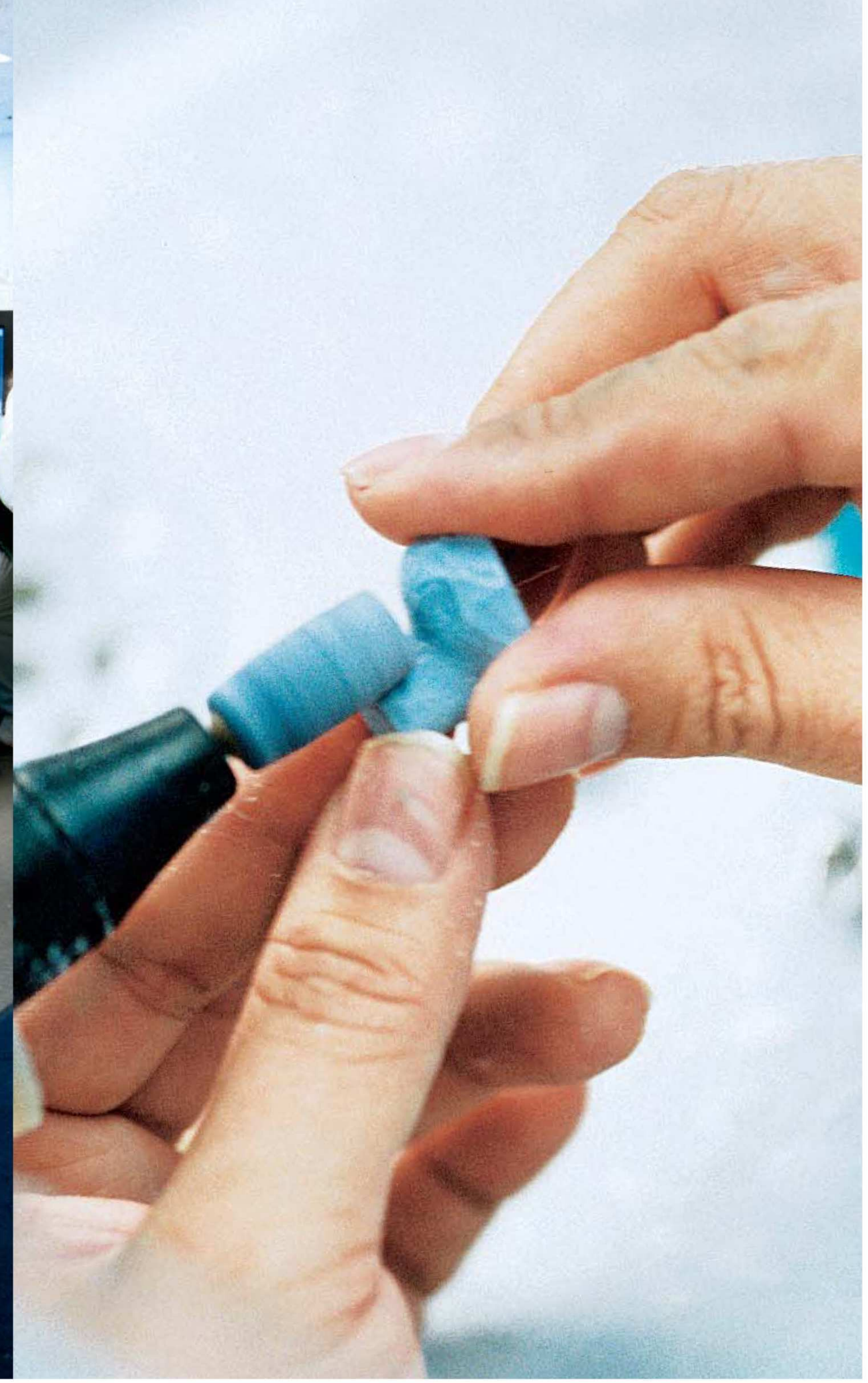
Until neuroscientists begin to figure out how the brain controls pain, blocking ion channels could prove the best way to find highly potent painkillers with few side effects. These drugs may not be the last word in analgesia, but if human tests confirm the drugmakers' theories, they will finally make morphine and its cousins obsolete. That's good news for Vicki Wiltshire, Elaine Casanova, and the millions like them who suffer from devastating pain. TR

Ken Garber is a freelance science writer based in Ann Arbor, MI.

INSTANT MANUFACTURING

From jet parts to hearing aids, the manufacture of finished goods directly from digital files and piles of powder is a growing trend. Someday, retail stores might even print out a product just for you. **BY IVAN AMATO** PHOTOGRAPHS BY MICHEAL MCLAUGHLIN

Factory in a box: Inside a direct-manufacturing machine (above), custom hearing-aid shells arise from nylon dust, lasers, and digital files. Direct manufacturing is replacing laborious manual techniques (right).



A boundary line of manufacturing history cuts across the factory floor of Siemens Hearing Instruments in Piscataway, NJ. On one side, skilled technicians use casting techniques, precision tools, and years of experience to craft the acrylic shells of hearing aids modeled from silicone impressions of actual ear canals.

On the other side of the factory floor, two pizza-oven-sized machines create similar shells from nylon dust. Inside the machines, needles of laser light, guided by digital design files, robotically scan back and forth, cinching paper-thin layers of dust into tough strata of plastic. Four hours and several hundred laser sweeps later, a batch of 80 hearing-aid shells is completed *(see "From Dust to Hearing Aids," this page)*. The process saves hours of human labor and produces hearing aids that fit and sound better than traditional ones.

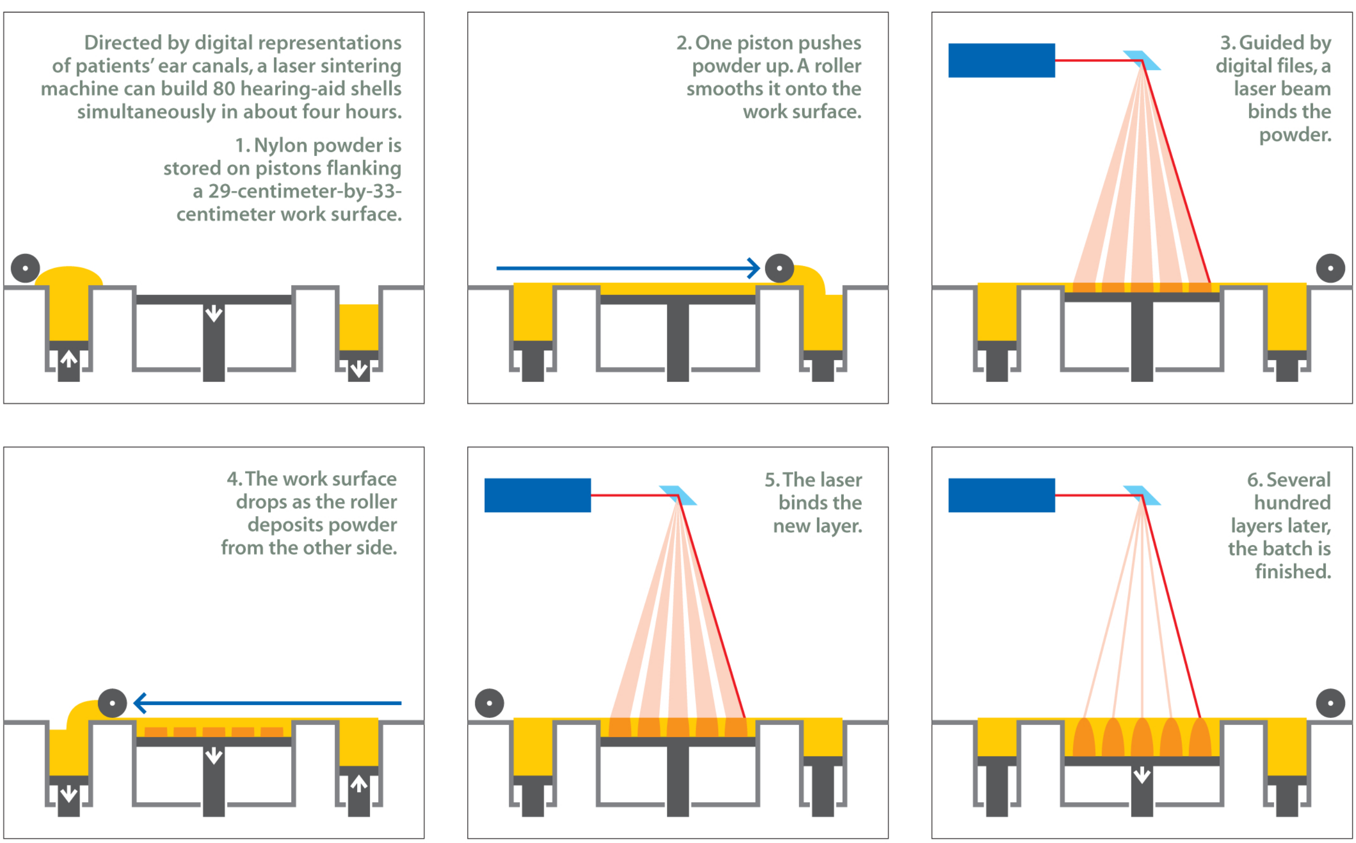
It works so well that Siemens, the world's largest maker of hearing aids, is completely switching to the technology at several factories. "This whole process allows us to be more accurate and eliminate human error. This is going to change the business," says William Lesiecki, director of software and e-business solutions for Siemens Hearing Instruments.

Siemens's switchover is just one example of a surging trend in automated manufacturing. Robotics on the factory floor are, of course, nothing new. These days, everything from cars to pharmaceuticals comes off of heavily automated production lines. But direct-manufacturing machines go the next step, using only a digital file—whether created by an engineer or by a scan of a physical object—to custom-make products. They are, in essence, large three-dimensional printers. They both fabricate materials—for example, plastic or metal from powders, or nylon from resin—and shape them into parts. In short, they're a direct bridge between the virtual world of design and the physical world of manufacturing.

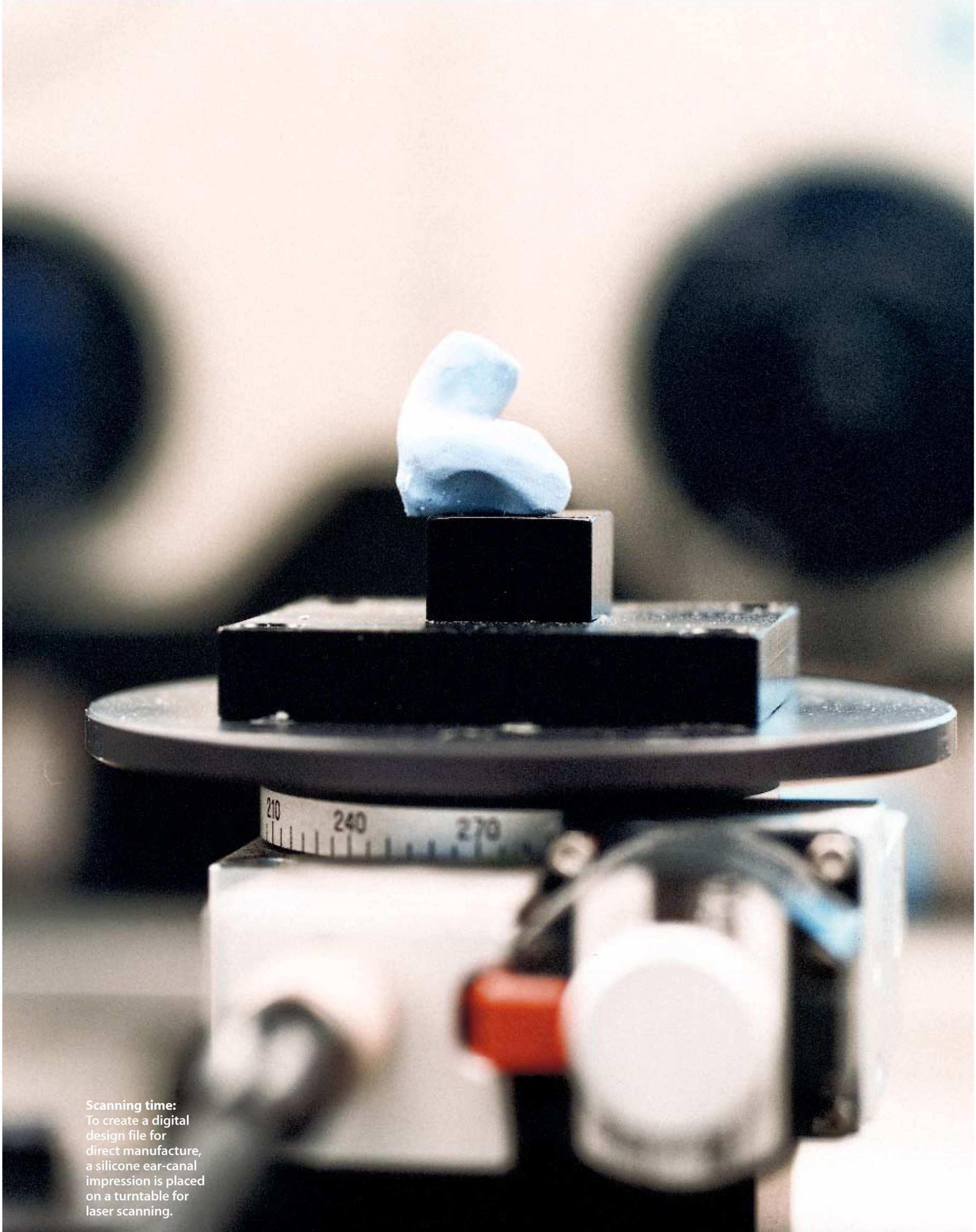
The technology is already beginning to displace conventional manufacturing in some areas, like specialized parts for jets. At On Demand Manufacturing, a Boeing subsidiary in Camarillo, CA, 60 complex tubes for the environmental systems inside fighter jets are printed out by machines similar to those at Siemens. Gone are the expensive, specialized molds and dies that these parts previously required. Gone are stringent limits on shape and design, and the months-long waits for custom parts. It's the wave of the future in aerospace, says Miller Adams, a Boeing vice president at the company's Phantom Works R&D organization. "We could have cost savings of 50 percent on specific parts," he says, easily adding up to millions of dollars per year. What's more, printing parts compresses manufacturing schedules by 50 percent as well. "We believe this will work for many industries outside aerospace," Adams adds.

Indeed, Siemens and Boeing are not alone: more and more companies are exploiting direct manufacturing, says computer scientist David A. Bourne, director of the rapid-manufacturing laboratory at the Robotics Institute of Carnegie Mellon University. Bourne says direct manufacturing will eventually become ubiquitous in the manufacturing sector. "I've been talking about this for 15 years, and now it's becoming real," he says. "In

FROM DUST TO HEARING AIDS



ALAN KIKUCHI



Scanning time: To create a digital design file for direct manufacture, a silicone ear-canal impression is placed on a turntable for laser scanning.

five years, it will be on most people's lists of the coolest technologies." Among the business benefits, he notes, will be the dramatic reduction or even elimination of costly overstock. Companies will only have to make products when "someone is standing there with a dollar bill to pay for it," he says. Then, the manufacturer will simply print one out.

For now, the examples of these printout products are somewhat arcane. Beyond hearing aids and jet ducts, they include electrical boxes for race cars, fine-mesh ceramic filters used in making soy sauce, and surfaces that guide air inside jet engines. But evidence of surging interest is unmistakable, says Terry Wohlers, an industry analyst in Fort Collins, CO. The number of machines doing rapid prototyping—a key progenitor of direct manufacturing—is approaching 10,000, and a small but growing percentage of these machines are now being used for direct manufacturing.

Breaking out: Pieces of replacement bone, complete with micropore structures, emerge from an ink-jet printing process.

Of course, not everything can be made with such machines, and nobody expects them to become as ubiquitous as laser printers: for one thing, the cheapest ones now cost around \$30,000 *(see "You Want One of Your Own?" p. 62)*. Direct manufacturing works best for relatively low-volume fabrication of high-cost items. Still, that describes multibillion-dollar markets in arenas as diverse as aerospace, medical devices, and even human bone replacement. "This will be a completely different way of doing things," says mechanical engineer Joseph J. Beaman of the Laboratory for Freeform Fabrication at the University of Texas. "You just push a button."

Boning Up

In some ways, direct manufacturing is a natural consequence of the relentless pressure to reduce the time it takes to move a product from concept, through design and development, to commercial reality. When computer-aided design and digitally controlled tools began infiltrating factories in the 1970s and 1980s, the stage was set for rapid prototyping, which uses printing technologies to create three-dimensional objects that serve as prototypes for, say, toys or car parts. With prototypes in hand in just hours—rather than the weeks or months hand-carving and casting once took—designers can more quickly refine products, and engineers can quickly detect and correct problems.

The first rapid-prototyping machines used lasers to bind successive layers of a liquid polymer—a process called stereolithography. Later versions used a broader range of raw materials, such as powders that would fuse together when hit by a laser beam. Another leap came in the 1990s, when the method expanded beyond lasers to include printheads that spewed binding liquids onto powders, adding speed and an even greater variety of materials *(see "Players in Direct Manufacturing," this page)*. At the same time, the push was on to develop these technologies to the point that they could make finished products, not just prototypes. "In the late 1980s, stereolithography had just come out, and it was very inspiring to see," says Emanuel Sachs, a mechanical engineer at MIT who developed the printhead method. "What I set out to do was to shift the focus from making prototypes to creating functional parts directly."

That goal has now been met. On a recent day at the Therics laboratory in Princeton, NJ, two employees in cleanroom suits watched as a car-sized printer made 300 two-centimeter-long chunks of substitute jaw bone. A linear array of eight printheads swept over successive layers of a powder called hydroxyapatite (the major mineral in natural bone), selectively dispensing tiny droplets of an organic binding liquid that would later be burned out during a furnace treatment. Under the relentless sequence of droplets—800 per second—the otherwise formless mass of powder began to take shape. The U.S. Food and Drug Administration approved Therics's bone substitute in late May, and while it hasn't yet been used in an implant in humans, it is already in the hands of surgeons who intend to test it soon. As

PLAYERS IN DIRECT MANUFACTURING

COMPANY	TECHNOLOGY	APPLICATIONS
3D Systems (Valencia, CA)	Selective laser sintering machines that use lasers to bind plastic or metal powders; stereolithography systems that cure liquid resins with laser-generated heat	Medical implants and prosthetics, military-jet components, hearing aids, Formula 1 race car parts
Stratasys (Eden Prairie, MN)	Heated plastic expelled by moving nozzles	Pump parts and small gears
Therics (Princeton, NJ)	Three-dimensional-printing technology, in which arrays of printheads spray droplets of organic binders onto powders	Bone substitutes with the porosity needed for cells to take hold after implantation
On Demand Manufacturing (Camarillo, CA)	The use of 3D Systems' sintering machine to create high-strength parts	Aircraft ductwork and other custom plastic and metal parts for aerospace applications
Siemens Hearing Instruments (Piscataway, NJ)	The use of 3D Systems' sintering machine to manufacture custom-fitted hearing-aid shells	Hearing-aid shells
Z (Burlington, MA)	Ultrafast three-dimensional printer that uses proprietary powders	Full-color geographical models for military planning

Good to the bone: A three-dimensional printer uses ink-jet printheads to make a trayful of replacement bone pieces.

a means of making replacement bone, direct manufacturing has some advantages. Say an accident victim has lost a fragment of arm bone. The piece can be digitally reconstructed using images of the same bone on the other arm. What's more, the printing technology is able to create pores just 50 micrometers wide, which allow the bone segment, once implanted, to host real cells that make real bone, strengthening and eventually supplanting the implant.

The FDA's approval of Therics's directly manufactured bone substitute is a milestone for the manufacturing technology. Indeed, Ranji Vaidyanathan, a materials scientist at Advanced Ceramics Research in Tucson, AZ—which is developing its own printed bone substitutes—expects directly manufactured bone to be common in three to five years. "I would say it will change the way we look at replacement bone," he says.

Testing the metal: These prototype rocket engine parts were made by laser-binding metal alloys, then baking them in a furnace.

Custom Robots

Bone implants presage far broader future applications that will follow improvements in speed, precision, and variety of raw materials. On Demand Manufacturing, which already makes plastic and metallic parts, hopes to offer materials that can perform under the most demanding of conditions, including the furnacelike heat of a rocket engine. The company has developed superalloy powders that can be shaped via direct-manufacturing machines and then baked into complex, superstrong turbine parts. The company is now taking the steps required to qualify the components for use in rockets.

Direct-manufacturing technology is going mobile, too. In a move that might one day have consequences for your local auto garage, the U.S. Army is developing truck-sized mobile units that can fabricate replacement parts—based on digital files or on-the-spot scans—for vehicles and weapons right on the battlefield.

And some are pushing the technology into the realm of robotics and electronics, complete with moving parts. As a first step, John Canny, Vivek Subramanian, and their colleagues at the University of California, Berkeley, are experimenting with ink-jet printing as a method for shaping organic semiconductors and electroactive materials into smart components that change shape in response to a voltage. One long-term vision is an all-polymer custom robot weighing less than one kilogram that could be printed for specific jobs, like fixing wiring in a tight spot on an airplane. But the Berkeley researchers' initial goals are more modest; Subramanian says they expect to build their first demonstration widget—perhaps a small movable joint—within two years.

The technology could eventually go retail, too. John Wooten, general manager of On Demand Manufacturing, envisions something like a chain of three-dimensional Kinko's equipped with direct-manufacturing equipment that could replicate pretty much any object that could be scanned or defined in a digital file. "It's possible to envision a guy with his '65 Mustang and a broken window handle going there to have a new handle made," Wooten says. In a similar vein, Carnegie Mellon's Bourne foresees new options in personal customization: cell phones, CD players, and all kinds of consumer products with shapes and colors specified by customers.

While these retail applications are still hypothetical, businesses are sprouting to serve manufacturers on a contract basis. Companies like Accelerated Technologies in Austin, TX, and Met-L-Flo in Geneva, IL, accept digital design files and make rapid prototypes—a concept that could evolve into custom-printing products for retail customers. If such a service does materialize, a neighborhood car restorer looking to duplicate a tiny piece of grillwork, or a homeowner replicating old trim, would find it akin to a digital Home Depot, with an infinite virtual stockroom of customized products. TR

Ivan Amato is a Maryland-based science writer and editor whose latest book, ***Super Vision: A New View of Nature***, comes out this month.

YOU WANT ONE OF YOUR OWN?

IN ALL LIKELIHOOD you own a laser printer, which would have been an extravagance 18 years ago. Does this mean a personal fabricator is on its way to your home? You'd scan in something that catches your eye—or download a digital file from the Internet—then hit the "print" button, and your fabricator would bind, glue, and otherwise mold a material into a cell-phone cover, custom-designed fork, action figure, or any number of other digitally definable three-dimensional objects.

Don't hold your breath. Most industry watchers still consider such a scenario a long way off. Earlier this year, no less a player than printer giant Hewlett-Packard floated the concept of a less-than-$1,000 device that could create three-dimensional objects from digital files. More recently, though, the company drew back from the idea. "All I can say is it's one of the things we are looking at. I can't say whether we are still looking at it or have abandoned it," said Dave Berman, an HP spokesman.

Indeed, direct manufacturing's trajectory to homeowner affordability looks long. Prices of industrial machines have dropped quite a bit, but the cheapest still cost $30,000. Even if prices drop below $10,000 in the next decade, predicts Terry Wohlers, an industry analyst in Fort Collins, CO, the most likely buyers of household replicators will be self-employed engineers, who could make prototypes in their home offices, and tinkerers who already have garages full of machine tools. A killer app for the home is hard to foresee. "Most people wouldn't be able to justify a $10,000 or even a $1,000 price tag," Wohlers says.

But for those who did take the plunge, their children might someday pull CDs off of cereal boxes and print out action figures from the latest movie blockbuster. Add the Internet to this scenario, and they'd e-mail handmade presents to friends—or at least to those with their own personal replicators.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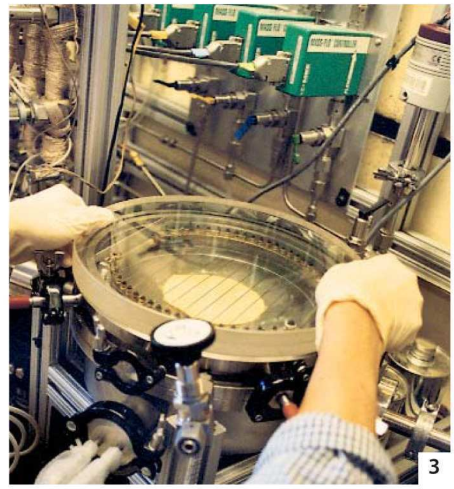
DEMO

WATERPROOF ANYTHING

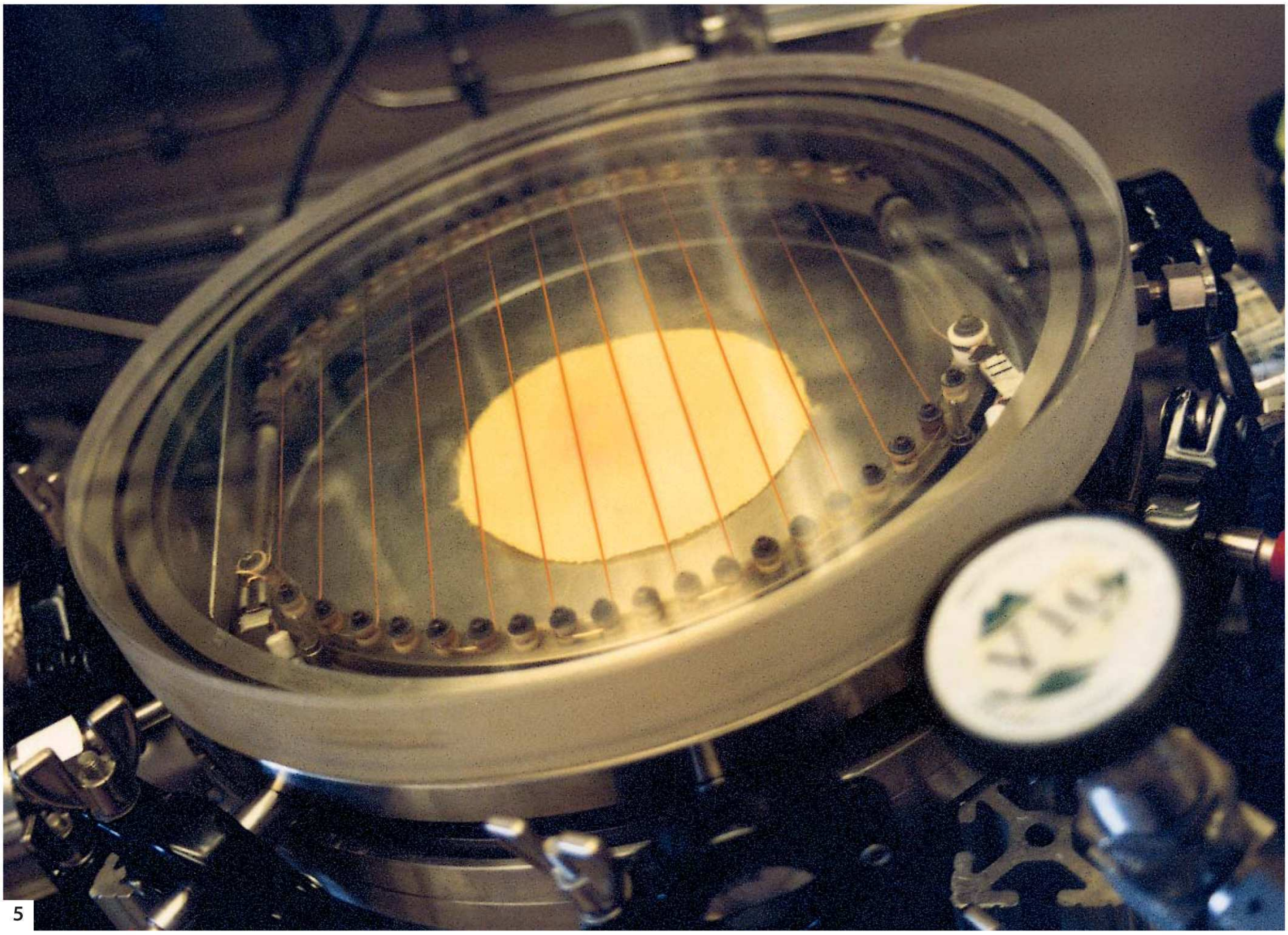
In **Karen Gleason**'s lab, Teflon's not just for frying pans. A new technique for depositing layers of the coating only nanometers thick on virtually any material lets her waterproof everything from textiles to tiny brain probes. Photographs by John Soares

MIT professor of chemical engineering Karen Gleason is a big fan of Teflon. "Teflon is really an amazing material and has a wide variety of applications," she says. It repels water, it's incredibly slippery, and it's biologically inert, which could make it ideal for coating rain gear, blades for shaving and surgery, and even tiny probes that monitor brain cells during neurosurgery. But the material, she says, "is also limited in the way it has been able to be applied to date." The problem lies not with Teflon itself, Gleason explains, but with the somewhat limited means manufacturers have for attaching it to other materials. Teflon typically starts as a powder, and "they spread the powder, say on a frying pan, and they basically just melt it," she says. The process doesn't create a strong bond between the Teflon and the underlying surface and, because it involves heat, it's useless for very delicate objects. What's more, it produces a coating that's too thick for intricate devices—in the case of a biological probe, thicker than the probe itself. But Gleason has developed a way to tightly bond very thin layers of Teflon to virtually any surface, by growing the long chainlike molecules link by link on the object she wants to coat. She showed *Technology Review* senior editor Rebecca Zacks how the process works by waterproofing a small sample of the bulletproof textile Kevlar.



1-3. Gleason adapted her technique to Kevlar—a material widely used in military gear—while working with MIT's new Institute for Soldier Nanotechnologies. "There are existing waterproof treatments for Kevlar, but they're very thick right now," she says. "In the flak vests that they have, there's several layers of Kevlar, and they're encased in a thing which is a water vapor barrier. It's not quite like having a steel plate, but almost. They're uncomfortable and soldiers wear them in their backpacks, where they don't do any good." Postdoctoral associate Kenneth Lau demonstrates a possible alternative, beginning by placing a yellow circle of Kevlar in a kettle-sized metal reactor chamber (1) where carefully controlled conditions will transform a precursor gas into a thin coating of Teflon. Lau next inserts a set of wire filaments into the chamber, so they rest about one centimeter above the Kevlar circle (2); these will heat the gas. He completes the setup by fitting a quartz cover on the top of the reactor (3).

4. With the turn of a valve, Lau creates a vacuum in the chamber. The negative pressure, Gleason explains, seals the cover and ensures that the gas will be distributed evenly. Controlling the pressure also helps control the chemical reactions, she adds; at higher pressures a Teflon powder would tend to form, rather than a film. Lau then flips a switch below the workbench, starting the flow of the gas. Gleason describes the gas: "It's a molecule that has three carbons, six fluorines, and one oxygen, and they're arranged in a way that the carbons form a three-membered ring, and that ring has quite a bit of strain. It's a pretty unhappy molecule."



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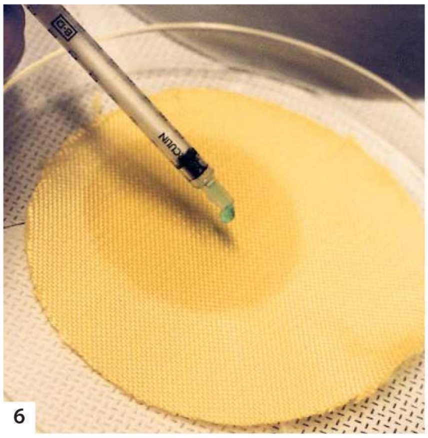
Waterproofing flak vests requires so many uncomfortable layers of material that "soldiers wear them in their backpacks, where they don't do any good."

5. Lau flips another switch and the filaments begin to glow a dull red. "With a little heat, the ring pops open and we get one unit off, which is the fundamental building block of the Teflon that we're making," says Gleason. "Once we have that fundamental unit, the idea is to get it to attach itself multiple times to form a very long carbon chain" on the surface of the Kevlar. For that to happen, she adds, the swatch of material must stay cool even as the filaments heat up to 450 °C, so a water pump circulates cold water through the metal plate on which the circle of material is resting. That way, the newly formed building-block molecules condense on the surface of the Kevlar "like dew forming on a window," Gleason says.

6-7. After a few minutes in the chamber, a 50-nanometer-thick Teflon film has grown on the surface of the swatch. The Kevlar looks and feels no different than it did before, but Gleason pulls out an untreated sample to show how differently it behaves. She drips water onto the untreated swatch, which quickly wicks it up (6). But water bounces and beads when it hits the treated Kevlar (7). Waterproofing is just the beginning of what the technology can do, Gleason says. "We showed you the vanilla version here," she says, but it's also possible to attach different types of molecules to the ends of the Teflon chains. Adding antimicrobial or toxin-sensing molecules, for instance, could yield textiles that protect their wearers from biological weapons as well as water.



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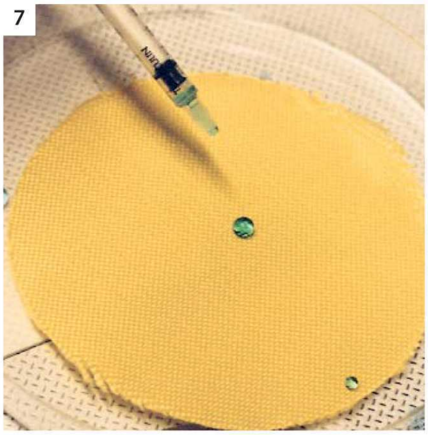

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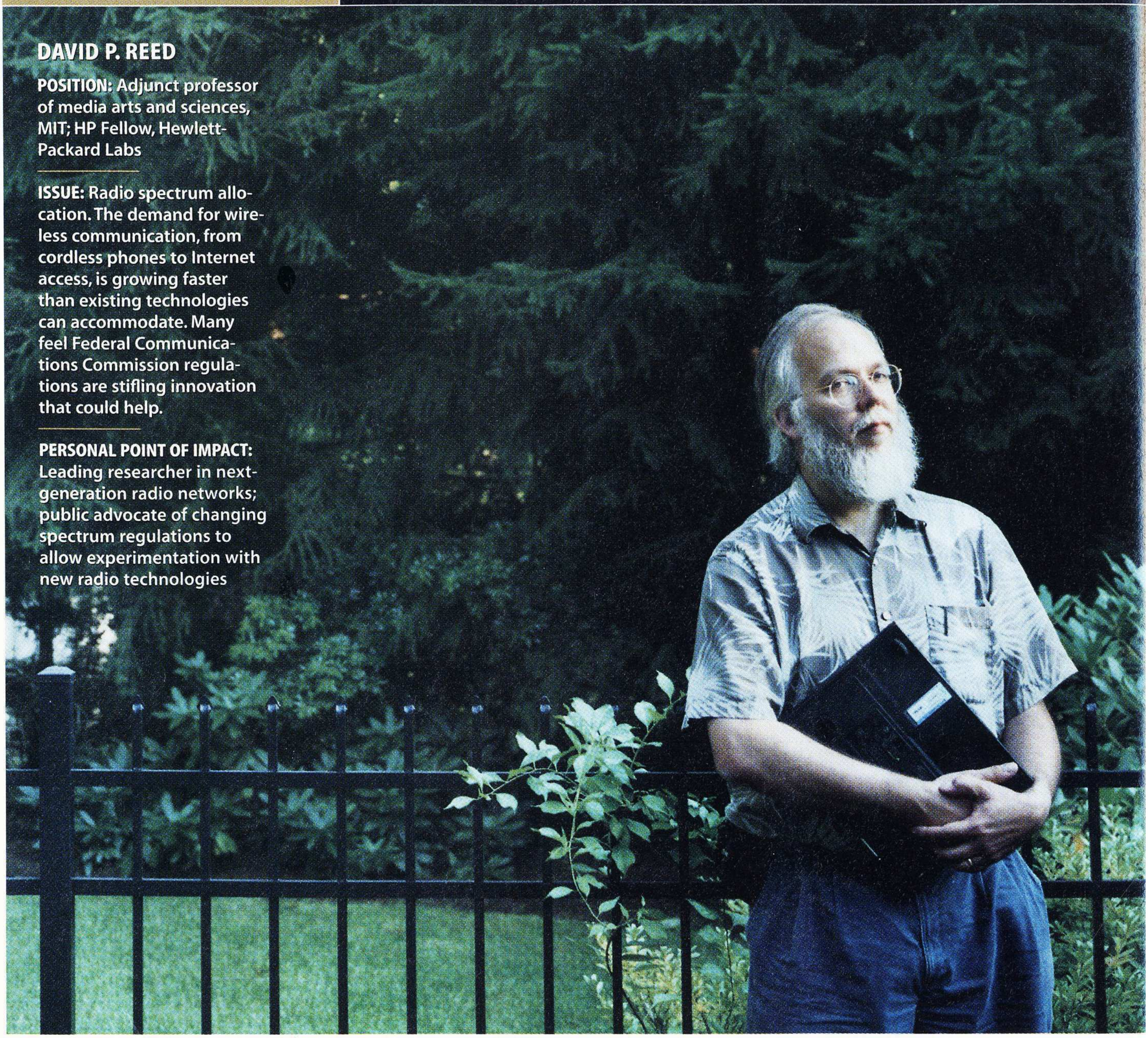

DAVID P. REED

POSITION: Adjunct professor of media arts and sciences, MIT; HP Fellow, Hewlett-Packard Labs

ISSUE: Radio spectrum allocation. The demand for wireless communication, from cordless phones to Internet access, is growing faster than existing technologies can accommodate. Many feel Federal Communications Commission regulations are stifling innovation that could help.

PERSONAL POINT OF IMPACT: Leading researcher in next-generation radio networks; public advocate of changing spectrum regulations to allow experimentation with new radio technologies

Radio Freedom

BY ERIKA JONIETZ | Photograph by Kathleen Dooher

TECHNOLOGY REVIEW: Why is our use of radio causing problems?

DAVID REED: There's clearly a huge demand for wireless digital communications that is driving high growth rates of services and devices, from traditional cell phones to Wi-Fi devices to other new things. We've gone from the idea where radio is an expensive thing that you only want to use when absolutely necessary to the idea that it's a convenience item for interconnecting everything, so my mouse and my keyboard talk to my computer by radio. The flip side of that is, what if we start doing that more and more as it gets cheaper and cheaper? Does everything start interfering with everything else, and do we have to pick what's allowed to talk to what? That's the question: how do you meet this overwhelming demand and overwhelming possibility with a sensible way of scaling up the use of radio.

TR: "Radio" brings to mind what we turn on when we get into the car, where a station broadcasts at a certain frequency, and if someone else uses that frequency, then we can't get our music or talk show. Is that not how all radio technologies work?

REED: Well, it's certainly not correct from the point of view of the technology. Long ago, when radio spectrum was wide open

and we weren't able to do very good radios, we decided that the best and cheapest way to allow many radios to operate on the same channel was to divide the spectrum up according to the application. So we have bands that are assigned to broadcast AM radio, bands for television, for two-way communication, and all that. We didn't think at all technologically about that; dividing by frequency was easy to do given the technology of the day.

In the past 10 to 12 years, we've started to realize many, many technologies can effectively share the airwaves without necessarily causing each other to malfunction. But the regulations that we and other countries apply to radio transmission don't admit that those new approaches are even legitimate. To get a new technology approved, especially one that contradicts the original assumptions, is virtually impossible—an incredibly political problem with lots of vested interests in keeping things the same.

TR: How does that play out practically with the Federal Communications Commission, which regulates airwaves in the United States?

REED: A really interesting example is what happened to ultrawideband. The company I was at before 1996—Interval Research—was looking at innovative technologies for very-short-distance networking, and one of the things we discovered, in its infancy, was ultrawideband. Interval financed a large investment in taking that technology from a research possibility to some commercial capabilities and spun off a company called Fantasma Networks.

Ultrawideband is a technology that uses very, very low energies in every band, so it theoretically should not interfere with existing services. But proving a negative—proving that it will not interfere with any existing service—is extremely difficult, and the FCC basically had to push ultrawideband through the approval process without that absolute certainty. For several years, the FCC delayed rulemaking on ultrawideband. The prospects of interference were the big issue. But underneath it all, there's also this issue of, if it was made legal, many services could move to ultrawideband, and then there

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would be unrestricted competition against existing providers of services. For example, you might see ultrawideband being used to provide television, or radio, or two-way telephone communication, and that would eliminate the monopoly or oligopoly benefits that come to the current spectrum holders. So they have a strong incentive to fight this. It's very hard to make a wise decision confronted with highly politicized technical arguments.

Fantasma continued to develop the technology, but approximately a year before the FCC finally allowed some ultrawideband, the investment community lost patience in this company, and it basically had to fold. It shows how the regulatory environment really stifles potential innovation that is crucial to solving this huge need of having much more capacious wireless networking capabilities that can work at all distances and scale to much larger numbers of devices and users than we have today.

TR: Are there other disadvantages to the current regulatory structure?

REED: There are several problems. One problem is that it's very hard to determine in advance what services will be successful. So if you try to put the FCC or some international body in charge of determining which are the most beneficial new technologies, you're putting the cart before the horse. If you can't try it out on real customers, then you have no idea what's going to work.

The second thing about the regulatory system is that—most people will agree—it's been captured by those that it regulates. If the FCC proposes any new thing, the first [group] they hear from is the lobbyists, who use a variety of arguments to either say it threatens their businesses or it threatens their technology. In the case of radio, it's almost always formulated as an argument about interference, even if the real issue is competition. And it's very hard to refute certain technical arguments, especially in a forum like the FCC: the FCC does not have a strong independent technical evaluation capability.

TR: So do new technologies such as ultrawideband really not interfere with, say, my cell phone or an airplane's electronics?

REED: Left to ourselves, I think engineers would be able to find solutions to almost any of these problems—should they turn out to be problems. For example, there is a whole lot of unused capacity in the current UHF television band. There's an FCC proposal to allow unlicensed use of that spectrum as long as the technologies being deployed don't interfere with existing users. Because that band propagates much better through trees and other sorts of things, it could enable a new generation of digital communications networks that could coexist with television, and that would handle longer-range communications better than Wi-Fi. There are a lot of potential engineering solutions to avoiding any interference that might be caused. Software-defined radios are now possible that can essentially dance around the existing television services. But it's very hard to make the case that this will work when you're basically facing political opposition, rather than technical opposition that wants to work with you.

TR: So what could improve the situation?

REED: I think the desirable future would create more opportunities for experimentation and follow-on. Right now there is a huge disincentive to even do research on novel kinds of systems, because it's considered extremely expensive and almost a waste of time to try to go through the FCC process for anything that's very different from what's currently out there.

The other side of that is creating regulatory openings that allow significant exploration. A really good thing that happened was the opening of the completely unlicensed spectrum that Wi-Fi and the new 802.11a wireless standards work on; [the Wi-Fi band] was authorized by the FCC in 1985, and the [802.11a] bands were authorized in the mid-1990s. The technology gradually evolved, and a networking standard was developed to increase interoperability in the late 1990s. We need more of these unlicensed bands—and of wider frequency—because people want more and more devices to communicate faster and faster, and today's Wi-Fi architecture doesn't scale to handle more users efficiently. New bands increase the rate at which innovations can be brought to market. TR

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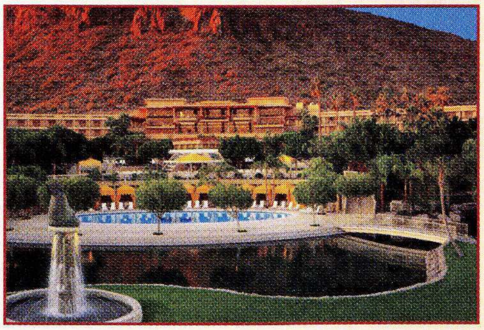

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The RNA Cure?

BY CORIE LOK

IT IS BEING HAILED AS ONE OF the biggest advances in biology in decades, one that could eventually lead to drugs for a wide range of diseases, from cancer to diabetes to AIDS. And one startup, Cambridge, MA-based Alnylam Pharmaceuticals, is in a particularly strong position to transform it into new pharmaceuticals.

In 1998, scientists discovered that RNA interference (RNAi)—a natural process in which small, double-stranded RNA molecules shut down the activity of particular genes—takes place in animals. For biomedical researchers, the implications were obvious; if you could selectively block genes involved in a disease, you could, in theory at least, stop it. Founded in 2002 by some of the pioneers of RNA interference research, Alnylam aims to synthesize small RNA molecules that could become the basis for a broad class of new drugs. So far, Alnylam has focused on cancer and metabolic diseases like diabetes. Its ambitious goal is to have a drug candidate in human testing by the end of 2005.

During its first year, Alnylam raised $43 million in venture capital, partially on the reputations of its scientific cofounders, who include MIT's Phillip Sharp, a Nobel laureate and cofounder of Biogen, and Paul Schimmel, a professor at Scripps Research Institute and cofounder of three biotech firms. And recently, Alnylam announced a partnership with Merck to develop RNAi drugs, the first deal with a major pharmaceutical company in the field of RNAi therapeutics.

From its beginning, building a solid patent position has been a big part of Alnylam's strategy. The company licensed technology from MIT, the Max Planck Institute, and others and has acquired a competing German RNAi company called Ribopharma, which held a crucial European patent covering the therapeutic use of small RNA molecules. Though none of its key patents has yet issued in the United States, Alnylam is confident that they will eventually cover the use of small RNA molecules as drugs.

Still, Alnylam faces major challenges in transforming the technology into actual treatments. "The real problem is delivery," says Judy Lieberman, a biomedical researcher at Harvard Medical School. While small RNA molecules promise to yield potent and specific drugs, they also degrade quickly in the body. That means Alnylam will have to devise a way to chemically modify the molecules so that they stick around long enough to do their job without losing potency or causing too many side effects.

And Alnylam is not without competition. This spring, Sirna Therapeutics in Boulder, CO, secured $48 million in financing, and it anticipates going into human trials with an RNA-based drug late next year. Sirna also claims to have wide patent coverage of both its RNAi drug technology and the chemical modification methods needed to stabilize the fragile RNA molecules. Indeed, each company is convinced that the other will have to license from it to develop RNAi drugs. "It's likely in the coming years that there will be some [intellectual property] negotiations to settle who has the proper rights," says Christophe Echeverri, CEO of Cenix BioScience, a Dresden, Germany, company that uses RNAi as a research tool in the drug discovery process.

Despite the tough technical and business challenges, Alnylam's CEO, John Maraganore, has big plans for the company: "We want to be a fully integrated company that's marketing and selling its own products." It's an ambitious goal for a young startup. But given the company's scientific lineage, it just may be achievable. TR

ALNYLAM PHARMACEUTICALS

HEADQUARTERS: Cambridge, MA

UNIVERSITY: MIT

INVESTMENT RAISED: $43 million

LEAD INVESTORS: Polaris Venture Partners, Cardinal Partners

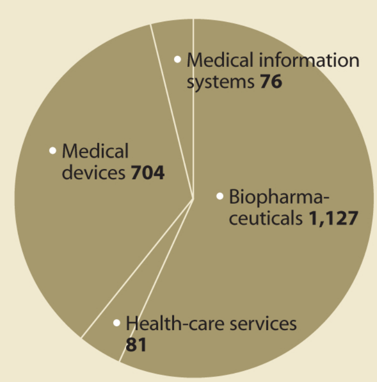
KEY FOUNDERS: David Bartel, Paul Schimmel, Phillip Sharp, Thomas Tuschl, Phillip Zamore

OTHER STARTUPS IN RNAi THERAPEUTICS

COMPANY	TECHNOLOGY
Sirna Therapeutics (Boulder, CO)	Synthetic small RNA molecules for hepatitis B and C and macular degeneration
Nucleonics (Malvern, PA)	Injectable DNA that serves as a template for RNA molecules that target hepatitis B and C
Benitec (St. Lucia, Queensland, Australia)	Injectable DNA that serves as a template for RNA molecules that target HIV, hepatitis B and C, and certain cancers, including leukemia
Acuity Pharmaceuticals (Philadelphia, PA)	Small-RNA-molecule drugs for macular degeneration and diabetic retinopathy

VENTURE FUNDING IN BIOTECH

AMOUNT INVESTED, FIRST HALF OF 2003 ($ million)



Cash invested by venture capital firms, corporations, and individuals in U.S. companies that have received at least one round of venture funding.

SOURCE: VENTUREONE/ERNST AND YOUNG (PIE CHART)

MIT technology insider

MIT Technology Insider is the only publication that follows the hundreds of innovative technologies conceived exclusively in the research labs and classrooms at MIT **AND** reports on patents issued, technologies licensed, and which companies are commercializing them.

MIT technology insider

FROM THE EDITORS OF TECHNOLOGY REVIEW

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KEY

	FUNDING
$	UNDER $2 MILLION
$$	$2 MIL–$10 MIL
$$$	$10 MILLION PLUS
	PATENT STRENGTH
	NO CORE PATENTS
	CORE PROTECTION
	DOMINANT POSITION
	TIME TO MARKET
	LESS THAN 1 YEAR
	1-3 YEARS
	MORE THAN 3 YEARS

SPIN-OFF SPOTLIGHT

Reworking Wireless

EMBER CORPORATION IS DEVELOPING A NEW KIND OF NETWORK—ONE IT HOPES WILL UNWIRE INDUSTRIES WHILE CREATING NEW MARKETS.

Considering the murky climate of today's wire- less communications industry, Adrian Tuck's cheery take on the history of Ember Corporation may seem surprising. "I would love to give you a horror story, but I can't," laughs the executive vice president of the Boston-based company. Spun off from MIT's Media Lab nearly two years ago by cofounders Robert Poor and Andrew Wheeler, the company has raised $28 million in a downright dreary climate for finding venture capital and is actually shipping product to paying customers. Not too shabby for a startup market- ing a technology that many IT experts doubted would even work.

Ember's technology is the hardware and software behind wireless sensor, or "mesh," networks. The systems consist of a series of small, low-powered nodes---circuit boards the size of a credit card---each contain- ing an eight-bit processor and a small antenna. Each node transmits a tiny amount of data---say the temperature reading of a water tank—to the nearest neighboring node, which then relays the message to the next node, and so on. The nodes quickly find the best route to bring the data to its destination: in this case, the thermostat that con- trols water temperature. Researchers at Ember want to create these self-configuring networks to carry out very simple, low-power tasks---like telling a light switch to dim or a heater to turn on---that don't require anything close to the signal strength of the Bluetooth or WiFi wireless systems used for larger data transmissions.

"Think streetlamps," says Poor, who received his PhD from the Media Lab in 2001. "Now, imagine if you put an Ember node in the ballast of every streetlamp in a city. First thing you can do is control the lamps more sensibly. You can find the ones that don't go on, and more important, the ones that are stuck on. Soon you have an entire city covered with this infrastructure."

And from there, says Poor, others would find reasons to keep adding to this network. For example, transportation companies could track bus schedules using nodes implanted on the buses themselves. As each bus passed a lamp, the node on the lamp could relay a message to the next bus stop, letting passengers know when the bus would arrive. Costs would be small because the backbone of the network would already have been laid out in the streetlamps. And that's just one off-the-cuff example. "We don't know what the killer app is yet," continues Poor, "but once the network starts growing, others will find more and more reason to join in."

EMBER

$$$

While several major companies and labs---among them Motorola, Intel, and the Palo Alto Research Center---also are exploring self-configuring networks, Ember's founders believe their routing algorithm, patented by Poor in 2000, sets the Boston startup apart. The code enables each node to decide two things: whether or not to pass a given message along, and which particular node it should then pass the message to—never sending a message to more than one node at a time. This prevents the network from being overwhelmed with too much redundant data.

The evolution of Ember's nodes is displayed in the company lobby. Five versions are arranged chronologically, starting with Wheeler and Poor's 1999 Media Lab prototype that Poor tested by "networking" his home garden. This original

CONTINUED ON PAGE 2

AN MIT ENTERPRISE TECHNOLOGY REVIEW

UNDERWRITTEN BY

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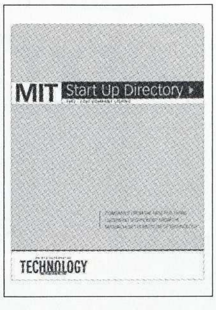

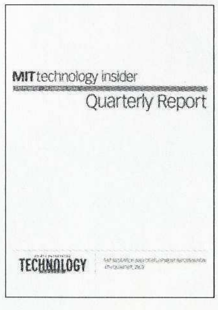

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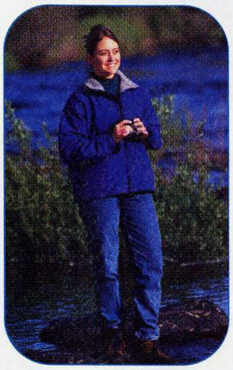

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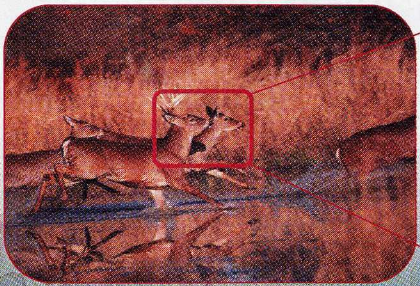

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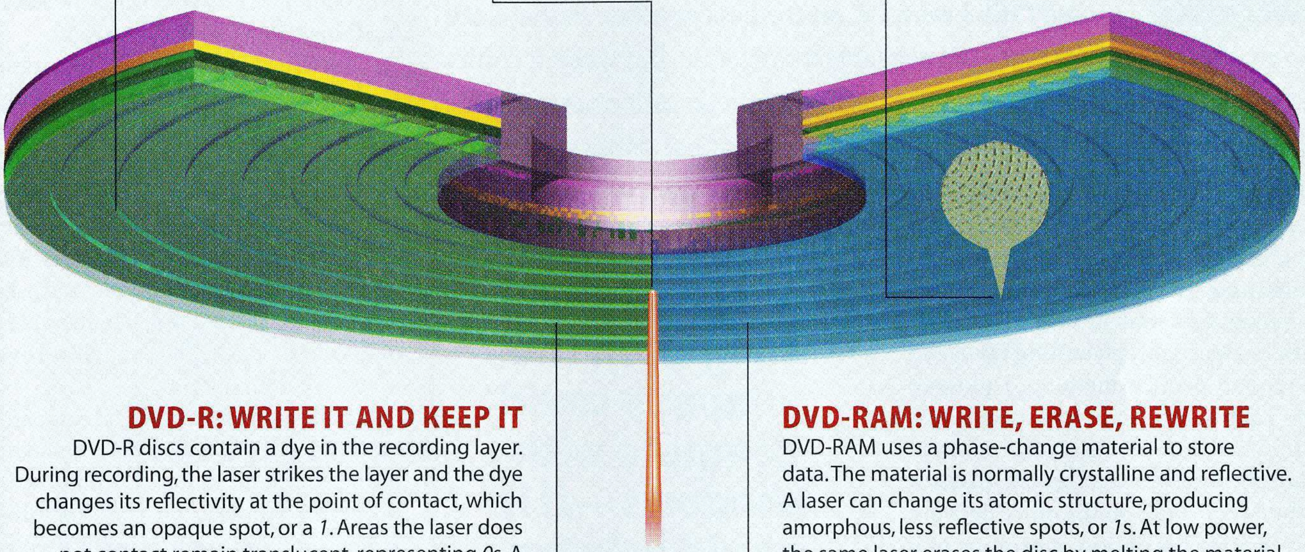
DVD Burners

DVD Burners pack seven times as much data as a CD can hold onto a disc that's the same size. The higher-density storage is made possible by the burner's red laser, which uses a much smaller wavelength of light than a compact-disc burner's. This beam can write up to 4.7 gigabytes of data—enough to store a two-hour movie or more than 13 hours of music—on a single-sided digital video disc. The lasers on some DVD burners can be adjusted to a lower power to allow data reading or rewriting, but that capability depends on the burner and the disc. Although there are many DVD formats, two of the most common are DVD-R (readable) and DVD-RAM (random-access memory). **TEXT AND ART BY REBECCA PERRY**

FROM THE BOTTOM: DVDs are written and read from below. A grooved track in the disc serves to guide the laser as it travels in a spiral from the center to the outside edge.

LASER: DVD burners use a laser that emits light at 650 nanometers—as opposed to 780 nanometers in CD burners. The DVD beam allows for more compact storage.

SEEING SPOTS: The laser burns spots into the DVD's recording layer, creating a pattern of low or high reflectivity that represents the *1*s and *0*s of digital data.

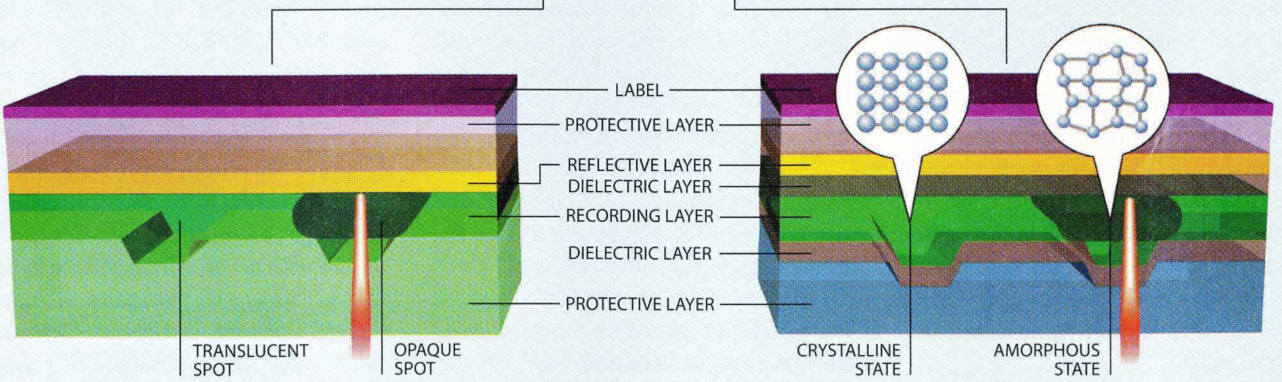


DVD-R: WRITE IT AND KEEP IT

DVD-R discs contain a dye in the recording layer. During recording, the laser strikes the layer and the dye changes its reflectivity at the point of contact, which becomes an opaque spot, or a *1*. Areas the laser does not contact remain translucent, representing *0*s. A DVD-R disc is written once for permanent storage and is compatible with most of the players on the market.

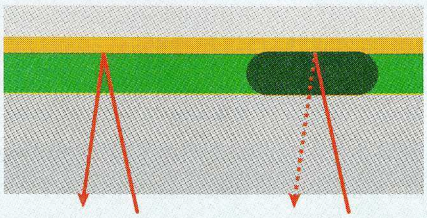
DVD-RAM: WRITE, ERASE, REWRITE

DVD-RAM uses a phase-change material to store data. The material is normally crystalline and reflective. A laser can change its atomic structure, producing amorphous, less reflective spots, or *1*s. At low power, the same laser erases the disc by melting the material, while "dielectric" layers above and below cool it back into the crystalline state. A DVD-RAM disc can be written and rewritten up to 100,000 times.



READING DVD-R AND DVD-RAM

READING *0*: A low-powered laser reads patterns burned on a disc. Where no spot has been recorded, the laser beam reflects back at full intensity. This light is read by a detector in the DVD player and converted by software into a *0*.



READING *1*: When the laser beam hits a spot recorded in the dye or phase-change material of the disc's recording layer, less light reflects back to the detector in the DVD player. The software interprets this as a *1*.

SOURCE: TONY JASIONOWSKI, PANASONIC TECHNOLOGIES

Apple-Picking Time in PC Land

MACS NETWORK BETTER WITH PCS THAN PCS DO! That's my conclusion after junking my Windows laptop and getting an Apple PowerBook G4. ■ Don't get me wrong: I still have a PC on my desk at home so that I can use all of that software that's not available for the Mac. But when it comes to Web browsing, reading e-mail, or jacking into an office network, the Mac is better. Apple always led the way in ease of use. Now something different is happening in the world of the Macintosh, and the rest of the tech community should take careful note: Apple is reinventing the personal computer.

Recently, I was in a friend's office with my Mac laptop running OS X and needed to print something. I plugged into his network and typed command-P in Microsoft Word: the Mac automatically discovered a Hewlett-Packard color laser printer on the office network and gave me the option of printing to it right from the "Print" dialogue box—no configuration required. The document printed flawlessly. I then unplugged the computer from the network and typed command-P again: the color printer had been automatically removed from the list of options. Very smart. This kind of transparent networking just doesn't happen with most PCs: you need to manually add the printer using the "Add Printer Wizard," then delete the printer when you don't need it anymore. Windows XP has a system for automatically discovering printers, but it frequently doesn't work.

A few weeks later, I was at an apartment where another friend had a Verizon DSL connection. My friend was sure that my Mac couldn't use the DSL link, because his Windows laptop needed special drivers to understand the PPPoE protocol that Verizon uses. I unplugged his PC, plugged in my Mac, opened up the network control panel, and checked the box that says "Connect using PPPoE." A moment later, I was on the Internet.

Apple is reinventing the personal computer. The company could compete with Windows—if it would only try.

But the real reason I love my PowerBook is the tight integration between the computer's hardware and software. When I open my computer's lid, it wakes up instantly; when I close the lid it suspends within two seconds. If I connect to a remote computer over the Internet and suspend my Mac, then wake it up a few minutes later, the connection is still there. Try that with a Windows or Linux machine and you'll lose your Net connection—if the machine goes to sleep at all.

I've had engineers from IBM stare at my Mac, and grumble that they wish their ThinkPads would act the same way—that is, as an instant-on, instant-off machine. That's unlikely to happen, though; such tight integration is difficult in the world of Windows, where more than 1,000 companies are developing hardware and software.

For many among the computer-using elite, the Macintosh has become the Dream Machine. That's because the Mac is a Unix system that can read Microsoft Word, Excel, and PowerPoint files. For most people, the ability to work with these documents is essential; although the free alternatives like Open Office perform well, they are not good enough for high-priced managers and consultants. But tech fetish appeal won't be enough to save Apple. As the company made clear in a recent ad campaign, what it needs is for people to "switch"—or at least to buy Macs to co-exist with their PCs. And here's the second big thing that Apple is doing right.

Back in the old days, Apple argued that to produce a truly usable computer, it had to build a machine that wasn't compatible with, and hence encumbered by the flaws of, the dominant PC design; Apple's products were as a result less flexible and more expensive than PCs. Apple's computers still cost too much, but the company is now much better able to justify that price through improved usability and functionality.

For the past five years, the company's hardware designs have been unmatched in the computer industry. And now the programs running on the Macintosh screen look beautiful as well: they are clean and simple, providing useful features without all of those frills that litter the Windows landscape. For example, Apple's Safari Web browser has a menu item that you can select that says "Block Pop-Up Windows." Want some privacy? The last item in the browser's "History" menu says "Clear History." On Windows, clearing Internet Explorer's history requires cycling through a confusing set of menus and options.

So with all this on its side, why isn't Apple making bigger gains in market share? In a word, arrogance. Despite its recent advances in compatibility, Apple still has a go-it-alone philosophy. The company must do better at encouraging application developers to sell versions of their programs for the Mac. It needs to sell a version of OS X that runs on standard PC hardware. Apple could compete with Windows—if it would only try. TR

Simson Garfinkel is an incurable gadgeteer, an entrepreneur, and the author of 12 books on information technology and its impact.

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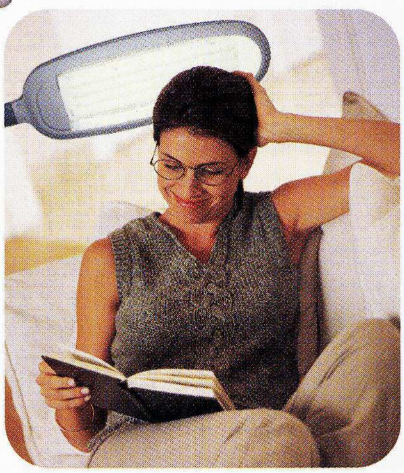

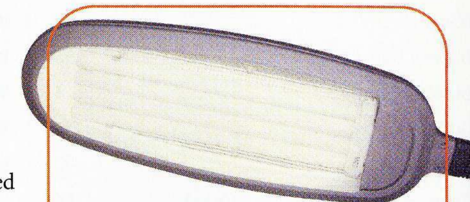

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The Voder at the 1939 New York World's Fair.

Vocal Codes

An early electronic speech synthesizer had a big influence on modern digital telephony. BY LISA SCANLON

Every time you make a digital cell-phone call, you take advantage of speech coding—the process of converting human speech into a simpler signal that can be transmitted more quickly. This technology has its roots in a quirky organ-like electrical speech synthesizer invented nearly 70 years ago by an AT&T researcher.

In the mid-1930s, Bell Labs electrical engineer Homer Dudley was attempting to create a speech synthesizer, hoping it could reduce the amount of bandwidth necessary to transmit speech over transatlantic telegraph cables. Dudley knew that sounds produced by the vocal cords are transformed into speech by small changes in the shape of the space inside the mouth, which amplify certain frequencies and damp others. Dudley realized he could measure these frequency variations by passing spoken words through a bank of 10 filters that gauged energy output over different portions of the audio spectrum. By applying the same variations to electronically generated tones, he was able to produce robot-like but intelligible speech. His device, the Vocoder, was a breakthrough, enabling speech transmission that used far less bandwidth than sending an entire speech signal directly, which is how telephones worked at the time.

Still, Dudley's device didn't get much attention until he showed a revised version, dubbed the Voder, at the New York and San Francisco World's Fairs in 1939. Instead of simply speaking into the device, a trained technician—usually a young female telephone operator—would shape tones into synthetic speech by simultaneously manipulating a series of keys and a foot pedal. The Voder made quite a splash at the fairs, but it didn't turn its predecessor, the Vocoder, into a widely used bandwidth-reducing device. Undeterred, Dudley found another use for the Vocoder a few years later—as a voice encryption device for defense communications during World War II.

Although Dudley's research didn't make him a household name, his work forms the foundation of the speech coding used in modern digital telephony. Edward Lee, a professor of electrical engineering and computer science at the University of California, Berkeley, learned about the Voder and Vocoder when one of Dudley's colleagues from Bell Labs played him old recordings from the devices. "I didn't realize that the concepts were as old as they were," says Lee. "It really was a very significant development, and it deserves a lot more attention than it gets." TR

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